



Technical Memorandum

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*Subject: **INTERIM DRAFT** - Focused Feasibility Study
Remediation of Volatile Organic Compounds
Former C-6 Facility, Los Angeles, California (Site)*

This memorandum presents the results of the focused feasibility study (FS) that CDM has completed for the former C-6 Facility (site). The purpose of the FS was to re-evaluate the site groundwater remediation approach and select the appropriate solution that will be effective, implementable, protective, reliable, robust (secondary containment, redundancy, etc), measurable (to confirm performance), relatively invisible, and preferably simple and cost effective.

1.0 Remedial Action Goals

Based on the Remedial Action Objectives (RAOs) provided in the initial Request for Proposal (RFP), CDM's Proposal dated October 10, 2005 and subsequent discussions with BRC, the overall goals of any proposed remedy are to:

- protect human health and the environment;
- comply with all applicable regulations;
- minimize potential short-term and long term liabilities and risks to BRC, including minimal negative impact on the on-site tenants and property owners (for e.g. installing additional

remediation infrastructure only in readily accessible areas of the site), and on the remediation efforts in the surrounding properties;

- minimize lateral and vertical migration of VOCs in groundwater both from onsite and offsite sources;
- minimize vertical migration of VOCs to the underlying Gage aquifer;
- reduce VOC mass in shallow groundwater especially in the source area (greater than 5,000 micrograms per liter [$\mu\text{g/L}$] of trichloroethylene (TCE) plume) to the extent reasonably achievable over the next two to three years;
- reduce VOC concentrations in groundwater to regulatory thresholds or practical technology limits;
- minimize total life cycle cost considering both onsite remediation and contribution to the regional groundwater remedy;
- not create undesirable byproducts in the aquifer or other media; and
- obtain regulatory approval for “no further active remediation” for groundwater (i.e. monitoring only).

In addition, the selected remedy shall:

- be amenable to relevant pilot testing and phasing not only in the distinct areas of the site (Lot 8, Sunrider B-sand, Sunrider C-sand, etc), but also in the source area and expanded source area (greater than 1,000 $\mu\text{g/L}$ TCE plumes), as appropriate to minimize risk and maximize effectiveness;
- not use injection of any impacted water or hazardous materials in the shallow subsurface (i.e. existing infrastructure) under any buildings;
- make use of the existing infrastructure only to the extent feasible, with minimal risk, and recognizing the limitations and the likelihood that minimal or none of the infrastructure may be used; and
- use double containment to the extent practicable for storage, handling, and/or transport of contaminated water and hazardous materials.

2.0 FS Framework

To accomplish this task, CDM first prepared an FS framework including development of potential remedial alternatives for consideration and screening criteria with which each alternative will be evaluated. The screening criteria were developed keeping in mind the remedial action goals discussed earlier in this memorandum. The FS framework was mutually agreed upon between BRC, Haley & Aldrich, and CDM prior to preparation of this focused FS. The agreed upon criteria and alternatives along with their descriptions are presented in Tables 1, 2, and 3.

The following sections present a discussion of the various alternatives along with the initial screening of the alternatives, including groundwater modeling simulations for the alternatives to evaluate electron donor delivery, extraction and containment capture zones. Where possible, all evaluation and data are present in referenced tables, graphs, and figures with this memorandum supplementing the information provided in the attachments

3.0 Development and Screening of Alternatives

CDM developed two sets of remedial action alternatives that were considered in the study. One set included the different types of remedial technologies that could be implemented at the site. The other set of alternatives were developed how implementation could be phased not only spatially but also to address zones and levels of contamination. The sets were developed such that they could be evaluated independently, so that this study would recommend technology or technologies for use and then method(s) of phased implementation.

3.1.1 Remedial Technology Alternatives

The first set of alternatives presents the remedial technologies that were considered applicable for implementation at the site. The list is not intended to be a complete list of possible alternatives, but rather a focused list based on discussions with BRC and Haley & Aldrich, CDM's knowledge of the site, CDM's experience with remedial technologies, and prior preliminary groundwater modeling at the site. CDM only evaluated technologies and approaches that were expected to be acceptable and comparable in terms of effectiveness, risk, and the other screening criteria.

Based on the analysis documented in the final Pre-Remediation Implementation Workplan (CDM, August 7, 2006), there were only 17 existing amendment wells (all in the Sunrider property) that were considered acceptable without further testing. Eighteen wells were found to be unsuitable for further use, and the remaining 297 wells required some amount of testing. However, for the purposes of evaluating alternatives using the existing infrastructure, it seems necessary to make reasonable judgment of which of these 297 wells should be considered usable, so that meaningful comparative analysis of the alternatives can be

performed. Future hydraulic testing may still be necessary if some or all of these wells are used, mainly in the Sunrider property.

Results of this additional brief evaluation for the purposes of the FS indicated a total of approximately 195 existing injection wells (estimated to be 87 total wells in Sunrider property and approximately 108 wells in Lot 8) that either performed well enough in the previous tests to be considered usable for the purposes of the FS or were constructed with larger diameter casing and are likely to be productive. Appendix A contains a discussion of this brief evaluation. It should be noted that the Lot 8 wells were constructed with more stringent quality controls (as indicated by BRC) than the Sunrider wells and are likely usable without further testing, especially those which are outside the building footprint.

The remedial technology alternatives are presented in Table 2.

3.1.2 Phased Implementation Alternatives

The second set of alternatives describes how the selected technology could be phased into operation and the evaluation looks at the potential benefit of early implementation versus cost and implementability concerns. For example, it might be preferable to implement the selected remedial technology in the C-Sand in the Lot 8 area first, followed by phased implementation at other area, so that remediation may begin earlier in that area. Another way of phasing would be to implement the alternative in one area or zone (i.e. B-Sand) to address the 5,000 µg/L contour followed by the phased implementation for the 1,000 µg/L contour in C-Sand.

The phased implementation alternatives are all presented in Table 3.

3.1.3 Preliminary Groundwater Modeling

As part of the initial screening, some preliminary modeling efforts were performed to assess the potential number and location of injection and extraction wells, the anticipated groundwater extraction and injection rates, and estimated treatment and capture zones that would meet the following objectives:

- In situ enhanced bioremediation (ISEB) with bioaugmentation and automated injection and recirculation of onsite water for addressing the 5,000 µg/L and 1,000 µg/L trichloroethylene (TCE) plumes, as appropriate.
- Implementation of a reactive bio-barrier zone at the downgradient site extent to prevent migration of concentrations of greater than 1,000 µg/L TCE off site.
- Pump and treat for containment of the 1,000 µg/L TCE plume to prevent it from migrating off-site.

This evaluation was performed to determine how several of the alternatives would perform with respect to screening criteria, especially minimization of risk to Boeing (protectiveness of Gage aquifer), confidence in technical effectiveness, minimization of site impact, minimization of cost, and expedited cleanup.

This modeling was intended to evaluate and provide a relative comparison amongst a range of remedial alternatives that are intended to be implemented, in a phased approach as necessary.

Based on these objectives, the following remedial technology alternatives were modeled for relative comparison:

Alternatives Using New and Assumed Useable Existing Infrastructure

- Alternative 1A – This alternative utilizes extraction wells to contain concentrations in excess of 1,000 µg/L in the B and C sands, combined with ISEB using slug injections at existing, useable treatment wells.
- Alternatives 1B/1D/1F – These alternatives use ISEB using a combination of continuously operated new angle drilled injection wells with periodic slug injections at existing treatment (or injection) wells with adequate and documented capacity for accepting the donor solution. New angle drilled injection wells would be used to supplement coverage to treat the target zones. These alternatives target concentrations of 5,000 µg/L in the B-Sand and 1,000 µg/L in the C-Sand. Extraction wells are placed to minimize off-site migration of TCE in areas greater than 1000 µg/L. These alternatives are identical for purposes of the comparative modeling evaluation, since in the first case (1B) extracted water is treated, if necessary, and discharged to the sewer, and potable water is amended and injected; in the second case (1D) all the extracted water is treated, amended and reinjected; while in the third case (1F), all the extracted water is amended without treatment and reinjected.
- Alternatives 1E/1G – Revision of Alternative 1D consisting of ISEB using a recirculation approach with a combination of new angle drilled injection wells and existing wells with adequate injection capacity. Continuous injection would occur at all treatment wells. Extraction wells are placed to minimize off-site migration of TCE in areas greater than 1000 µg/L. These alternatives are identical for purposes of the comparative modeling evaluation, since in the first case the extracted water is treated prior to reinjection whereas in the second case no treatment is included.

Alternatives Using New Infrastructure Only

- Alternative 2A – This alternative is a containment alternative which is designed to capture concentrations greater than 1000 µg/L and discharge this water after any necessary treatment. This is similar to Alternative 1A, except no ISEB component is included.

- Alternative 2C – This alternative implements a reactive bio-barrier approach, where an array of injection and extraction wells at the downgradient extent of the site is utilized to minimize migration of concentration in excess of 1,000 µg/L off site.
- Alternatives 2B/2D/2E - These alternatives use an ISEB approach, with new angle wells under buildings and extraction wells. These alternatives target concentrations of 5,000 µg/L in the B zone and 1,000 µg/L in the C zone. Extraction wells are placed to minimize migration of concentration greater than 1,000 µg/L off-site in both the B-Sand and C-Sand. These alternatives are identical for purposes of the comparative modeling evaluation, since in the first case (2B) extracted water is treated, if necessary, and discharged to the sewer, and potable water is amended and injected; in the second case (2D) all the extracted water is treated, amended and reinjected; while in the third case (2E), all the extracted water is amended without treatment and reinjected.

Alternative 3A (Slug injection of donor into existing assumed useable wells) was not evaluated in detail in the model, since earlier evaluations have shown it to be not effective. For the same reason, Alternative 1C (pump and treat with reactive biobarrier with slug injection into existing assumed useable wells) was not modeled as this is similar to Alternative 2C without slug injection.

Appendix B contains additional information on the data and assumptions used in performing the preliminary modeling.

4.0 Focused Feasibility Study Results

CDM used the remedial action goals, screening criteria, and both sets of alternatives to perform the screening for the FS. The results are organized as follows:

- Evaluation of Remedial Technologies Alternatives:
 - Table 2 presents the individual and overall numeric ratings for each alternative
 - Table 4 presents the explanation and the logic behind the numeric ratings provided in Table 2
- Tables 3 and 5 present similar results associated with the evaluation of Phased Implementation Alternatives.

All the tables are organized according to what infrastructure each alternative uses. Alternatives that use existing and new infrastructure are separated from alternatives that use only new infrastructure and use only existing infrastructure. The results tables (Tables 2 and 3) also include lists of relevant assumptions and a key that describes the rating.

Appendix B contains the results of the preliminary modeling along with graphical depictions of the results for each alternative. The results of the modeling have been incorporated into the FS evaluation tables.

5.0 Conclusions

Based on the data presented in this memorandum, CDM has identified two preferred alternatives and two other alternatives were selected as secondary options. These are discussed below:

5.1 Preferred Remedial Technology Alternatives

Alternative 1F is one of two preferred methods of implementation. Modeling results show that it is extremely effective. The new injection wells under this alternative would include angle wells drilled beneath buildings that are operated at higher injection rates in order to increase groundwater velocities and allow greater spread of the donor compound before it is consumed. It is less effective than performing continuous injection into existing wells (Alternative 1G). However, 1G is not recommended due to the potentially high risk associated with continuous injection of untreated amended water into existing infrastructure. Using extraction and recirculation will provide several advantages over most other alternatives: the implemented system would be flexible, would remediate the site more rapidly, would lead to permanent site conditions, and would be relatively easy to implement. It is not the least risky alternative, as it does involve some slug injection into existing wells. However, these slug injections will not involve contaminated site groundwater, so this alternative is less risky. The system will utilize double-contained piping and potentially leak detection in pipes carrying impacted groundwater.

Alternative 2E is the other preferred method of implementation. Alternative 2E is expected to be somewhat similar to 1F in terms of effectiveness, with somewhat less coverage because the existing network would not be used. The new angle wells would maximize coverage without contacting existing wells, but would not be likely to achieve the same influence as the existing network of amendment wells. However, the other benefits of 2E are similar to 1F: no treatment costs, minimal risk, flexible implementation, favorable permanence, and fairly rapid site remediation, especially when compared to containment-based alternatives. In addition, the risks are lower and implementability is higher than those for 1F because existing infrastructure is not used at all.

5.2 Secondary Remedial Technology Alternatives

Alternative 1E did not receive an overall high rating, but scored the highest on risk minimization, and therefore is worth some consideration. The additional cost and schedule impacts required for complex treatment of extracted water to maximum contaminant levels (MCLs), non-detects or other risk-based thresholds prior to reinjection could be significant,

but it does provide a much safer alternative that would be fairly effective, with only some reduction due to the inability to recirculate microbial populations. However, the full complement of new and existing site wells would be usable with much lower risk, so additional coverage may offset lower microbial populations.

Alternative 1B is also fairly risk averse, because no impacted groundwater is being reintroduced. This alternative is fairly effective and does not require as much treatment (since it is discharged to the sewer) as Alternative 1E, so the treatment system would be simpler and more cost effective. However, the cost of fresh water necessary for implementation could be prohibitive. If the water is available at a reasonable cost, this alternative might be worth additional consideration as well.

5.3 Preferred Phased Implementation Alternatives

BRC has indicated that expediting implementation of the remedy is one of the critical success factors, and that implementing a pilot -scale/small-scale system capable of expansion as needed that incorporates low risk and low site disturbance that is effective, is strongly preferred over a non-phased site-wide alternative that will take time to plan, design, and implement.

There are several advantages to selecting an phased implementation alternative that focuses on the C-Sand and/or the Sunrider property, including reducing potential impacts to Gage aquifer and minimizing off-site migration downgradient of the site. However, significant coordination efforts would be required to install new infrastructure at the Sunrider property due to ongoing construction activities associated with site improvements. Furthermore, any implementation using existing infrastructure on the Sunrider property will require more hydraulic testing. Since protection of the Gage aquifer is one of the key goals listed in Section 1.0, some phased implementation should be performed at the Sunrider property regardless of coordination issues.

Phased implementation at Lot 8 would require less coordination relative to Sunrider. Furthermore, based on review of available data from BRC, the existing infrastructure on Lot 8 is expected to be far more robust and reliable than the infrastructure in the Sunrider area and several of the existing amendment wells on Lot 8 are outside the existing building footprint further minimizing overall risks.

Based on the above discussion, the preferred phased implementation alternatives are those that are associated with at least the C-sand and potentially B-Sand at Sunrider and with both zones at Lot 8 (Alternatives 4E and 4F).

Attachments:

Table 1 – Explanation of Evaluation Criteria

Table 2 – Evaluation of Remedial Technology Alternatives

Table 3 - Evaluation of Phased Implementation Alternatives

Table 4 - Explanation of Remedial Technology Alternatives Evaluation

Table 5 – Explanation of Phased Implementation Alternatives Evaluation

Appendix A - Brief Evaluation of Existing Amendment Wells

Appendix B - Preliminary Groundwater Modeling

Table 1
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Explanation of Evaluation Criteria

Criterion	Description
Minimization of Risk to Boeing	"Risk of Uncontained Release" Includes risk from unintended discharges (e.g. piping failures), unintended exposures, bad publicity, and other unintended consequences that would require additional action by or cost to BRC. Includes minimizing impacts to the Gage Aquifer and to offsite areas. Also includes risk from discharging to sewer without treating to MCLs/ND.
Confidence in Technical Effectiveness	Characterizes likelihood of obtaining desired objectives such as hydraulic containment and groundwater cleanup, and includes measure of how technically proven each alternative is
Implementability / Practicality	Describes the practicality of implementing each alternative, and how few significant logistics and challenges would be expected to be encountered during installation, operation, and monitoring. Also includes ease of obtaining regulatory approvals and permits.
Minimization of Site Impact	Measures how each alternative will minimize the visual impact to the site (Lot 8 Tenants and Sunrider) and maximize the future functionality of the site. Includes potential impacts to existing site operations during the various phases and acceptability to the site owner(s)/tenant(s).
Minimization of Cost	Presents how each alternative will minimize expected costs of implementation, operation, and monitoring. Evaluates the anticipated most likely cost range, the risk of exceeding that cost range and the opportunities for cost savings.
Flexibility	Ranks each alternative with respect to how well it would allow for future operational changes or for pursuit of different remediation objectives i.e. for addressing 5000 ppb or 1000 ppb contours
Expedited Implementation	Accounts for differences among the alternatives with respect to how quickly remediation can begin . This involves estimated schedules for performing additional studies and data collections, completing system design, obtaining permits, and constructing system. Does not include operation and maintenance phases.
Expedited Cleanup	Accounts for differences among the alternatives with respect to how quickly they will remediate the site after full-scale construction and implementation is completed. Phased implementation alternatives that address areas with the higher concentrations are scored better here as well.
Permanence	Addresses how well each alternative will lead to stable long-term site conditions, and gives preference to destructive technologies over technologies that transfer contaminants from one location to another or from one media to another. Also includes an evaluation of how the alternative might impact the big picture/surrounding site plumes (for e.g. P&T might pull contaminants in from other site).
Minimization of Need for Studies	Grades alternatives with respect to how much additional data is needed to complete design, implementation, and monitoring, and is directly related to additional cost and schedule impact

Table 2
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Evaluation of Remedial Technology Alternatives

Alternative Name		Description	Minimization of Risk to Boeig	Confidence in Technical Effectiveness	Implementability / Practicality	Minimization of Site Impact	Minimization of Cost	Flexibility	Expedited Implementation	Expedited Cleanup	Permanence	Minimization of Need for Studies	Recommended for Implementation
Using New and Existing Infrastructure													
1A	Pump & Treat (P&T) with sewer discharge; Slug Injections into existing wells	Extraction from new wells, treatment, discharge to sewer, with slug injections of nontoxic electron donor slug into siphoning existing wells as desired. This alternative would target the 1000 ppb contour in both aquifers.	3	2	4	3	1	5	5	2	1	2	2.8
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	Continuous injection of amended fresh water into new wells, with pump and treat (groundwater extraction from new wells, treatment, and discharge to sewer) and slug injections of nontoxic electron donor slug into siphoning existing wells as desired. This alternative targets concentrations of 5,000 ppb contour in the B-Sand and 1,000 ppb contour in the C-Sand. Extraction wells are placed to minimize migration of concentrations greater than 1,000 ppb off-site in both the zones.	3	4	2	2	1	4	4	4	3	2	2.9
1C	P&T with Reactive Biobarrier Slug injections into existing wells	Groundwater extraction from new wells located at distal extent of plumes (at downgradient boundary near Francisco Street), treatment of a portion of the water and discharge to sewer to maintain partial inward gradient within treatment area (i.e. maintain vertical and horizontal plume containment), amendment of remaining portion and convey via double contained pipe to new injection wells upgradient to maintain a reactive zone to mix with groundwater continuing to flow downgradient, and slug injections of nontoxic electron slug donor into siphoning existing wells as desired. This alternative would target the 1000 ppb contour in both aquifers, as a result of its placement at site boundary.	1	1	2	3	1	2	2	1	1	2	1.6
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	Groundwater extraction from new wells, treatment, amendment, continuous reinjection into new wells, with slug injections of nontoxic electron donor into siphoning existing wells as desired. This alternative targets concentrations of 5,000 ppb contour in the B-Sand and 1,000 ppb contour in the C-Sand. Extraction wells are placed to minimize migration of concentrations greater than 1,000 ppb off-site in both the zones.	4	4	2	2	2	2	3	4	4	1	2.8
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	Groundwater extraction from new wells, treatment, amendment, continuous reinjection into new wells and siphoning existing wells. This alternative targets concentrations of 5,000 ppb contour in the B-Sand and 1,000 ppb contour in the C-Sand. Extraction wells are placed to minimize migration of concentrations greater than 1,000 ppb off-site in both the zones.	4	4	1	1	3	2	3	4	4	1	2.7
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	Groundwater extraction from new wells, amendment, reinjection through double-contained piping into new wells only, with slug injection of nontoxic electron donor into existing wells as desired. This alternative targets concentrations of 5,000 ppb contour in the B-Sand and 1,000 ppb contour in the C-Sand. Extraction wells are placed to minimize migration of concentrations greater than 1,000 ppb off-site in both the zones.	3	5	4	2	3	5	5	5	5	2	3.9
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	Groundwater extraction from new wells, amendment, reinjection through double-contained piping into new wells and existing siphoning wells as desired. This alternative targets concentrations of 5,000 ppb contour in the B-Sand and 1,000 ppb contour in the C-Sand. Extraction wells are placed to minimize migration of concentrations greater than 1,000 ppb off-site in both the zones.	1	5	3	1	4	5	4	5	5	2	3.5

Table 2
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Evaluation of Remedial Technology Alternatives

Alternative Name		Description	Minimization of Risk to Boeing	Confidence in Technical Effectiveness	Implementability / Practicality	Minimization of Site Impact	Minimization of Cost	Flexibility	Expedited Implementation	Expedited Cleanup	Permanence	Minimization of Need for Studies	Recommended for Implementation
Using New Infrastructure Only													
2A	P&T with sewer discharge	Extraction from new wells, treatment, discharge to sewer. This alternative would target the 1000 ppb contour in both aquifers.	4	2	5	4	1	5	5	2	1	3	3.2
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	Continuous injection of amended fresh water into new wells with pump and treat (groundwater extraction from new wells, treatment, and discharge to sewer). This alternative targets concentrations of 5,000 ppb contour in the B-Sand and 1,000 ppb contour in the C-Sand. Extraction wells are placed to minimize migration of concentrations greater than 1,000 ppb off-site in both the zones.	4	3	3	2	1	4	4	4	3	3	3.1
2C	P&T with Reactive Biobarrier	Groundwater extraction from new wells located at distal extent of plumes (at downgradient boundary near Francisco Street), treatment of a portion of the water and discharge to sewer to maintain partial inward gradient within treatment area (i.e. maintain vertical and horizontal plume containment), and amendment of remaining portion and convey via double contained pipe to new injection wells upgradient to maintain a reactive zone to mix with groundwater continuing to flow downgradient. This alternative would target the 1000 ppb contour in both aquifers, as a result of its placement at the site boundary.	1	1	3	3	1	2	2	1	1	3	1.8
2D	P&T, Continuous injection of amended GW into new wells	Groundwater extraction from new wells, treatment, amendment, reinjection into new wells. This alternative targets concentrations of 5,000 ppb contour in the B-Sand and 1,000 ppb contour in the C-Sand. Extraction wells are placed to minimize migration of concentrations greater than 1,000 ppb off-site in both the zones.	4	3	2	2	3	2	4	4	4	2	3.0
2E	Pump (no treatment) Continuous injection of amended GW into new wells	Groundwater extraction from new wells, amendment, reinjection through double-contained piping into new wells only. This alternative targets concentrations of 5,000 ppb contour in the B-Sand and 1,000 ppb contour in the C-Sand. Extraction wells are placed to minimize migration of concentrations greater than 1,000 ppb off-site in both the zones.	3	3	4	2	4	5	5	5	5	3	3.9
Using Existing Infrastructure Only													
3A	Slug Injection	Slug injection of nontoxic electron donors into existing siphoning wells	1	1	2	5	4	1	4	1	1	2	2.2

Assumptions:

All new piping will be dual contained when conveyed fluids are impacted and/or injectant is hazardous.
Nontoxic electron donor injections into existing wells will not exceed 1 psig injection pressure.
New wells may include angled wells where modeling demonstrates need.
Some additional studies will be necessary almost regardless of which alternative is selected (e.g. Aquifer Performance Tests).
All alternatives that do not include some new injection/in-situ treatment component (i.e. 1A, 1C, 2A, 2C, 3A) will have to target the 1000 ppb contour, as wells cannot be placed to target the 5000 ppb contour due to pre-existing surface constraints.
Scores under the criterion "Recommended for Implementation" is an average of the scores for all other criteria, where all criteria are weighted equally.
The Score under the criterion "Confidence in Technical Effectiveness" is based on preliminary hydraulic modeling
The score under criterion "Minimization of Cost" is a preliminary qualitative evaluation of each alternative. Further quantitative evaluation will be done on the selected alternatives for the final FS

Scoring

- 5 Very Favorable, Ideal
- 4 Favorable, Good
- 3 Somewhat Favorable or Uncertain
- 2 Unfavorable
- 1 Very Unfavorable

Table 3
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Evaluation of Phased Implementation Alternatives

Alternativ Name		Description	Minimization of Risk to Boeing	Confidence in Technical Effectiveness	Implementability / Practicality	Minimization of Site Impact	Minimization of Cost	Flexibility	Expedited Implementation	Expedited Cleanup	Permanence	Minimization of Need for Studies	Recommended for Implementation
Phased Implementation Using New and/or Existing Infrastructure													
4A	Lot 8 - B Sand	Phased implementation of selected alternative, beginning in Lot 8, B sand	2	2	5	2	2	5	5	2	3	3	3.1
4B	Lot 8 - C Sand	Phased implementation of selected alternative, beginning in Lot 8, C sand	3	2.5	5	2	2	5	5	1	3	3	3.2
4C	Sunrider - B sand	Phased implementation of selected alternative, beginning in former Building 2 area, B sand	4	3	2	2	2	5	3	3	3	3	3.0
4D	Sunrider - C sand	Phased implementation of selected alternative, beginning in former Building 2 area, C sand	5	3	2	2	2	5	3	3	3	3	3.1
4E	Sunrider	Phased implementation of selected alternative, beginning in former Building 2 area (both zones)	4	4	2	2	2	5	4	3	3	3	3.2
4F	Lot 8	Phased implementation of selected alternative, beginning in Lot 8 area (both zones)	3	3.5	5	2	2	5	4	2	3	3	3.3
4G	B sand	Phased implementation of selected alternative, beginning in the B sand (both areas)	3	3.5	3	1	2	5	4	3	3	3	3.1
4H	C sand	Phased implementation of selected alternative, beginning in the C sand (both areas)	5	4.5	3	1	2	5	4	2	3	3	3.3
4I	No phasing	Implementation of selected alternative without phasing, using new and existing infrastructure.	3	5	5	3	3	2	2	4	3	3	3.3

Assumptions:

Phased implementation would be performed to begin remediation sooner, to conduct extended pilot tests, or to handle difficult logistics in certain areas (e.g. postpone implementation at Sunrider during their construction). However, even if one area is addressed first, other areas will be addressed second, with no change in scope other than modifications based on lessons learned during the early implementation. No additional significant costs are assumed due to major lessons learned, as it is assumed that sufficient studies and design work will be completed regardless of phasing. All new piping will be dual contained when conveyed fluids are impacted and/or injectant is hazardous. Nontoxic electron donor injections into existing wells will not exceed 1 psig injection pressure. New wells may include angled wells where modeling demonstrates need. Some additional studies will be necessary almost regardless of which alternative is selected (e.g. Aquifer Performance Tests) . The criterion "Recommended for Implementation" is an average of the scores for all other criteria, where all criteria are weighted equally. The score under criterion "Minimization of Cost" is a preliminary qualitative evaluation of each alternative. Further quantitative evaluation will be done on the selected alternatives for the final FS. Other portions of the FS may be revised at that time as well (e.g. "Recommended for Future Implementation")

Notes:

For explanation of criteria, See Table 1

Scoring

- 5 Very Favorable, Ideal
- 4 Favorable, Good
- 3 Somewhat Favorable or Uncertain
- 2 Unfavorable
- 1 Very Unfavorable

Table 4
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Explanation of Remedial Technology Alternatives Evaluation

Alternative	Name	Rating	Explanation
Minimization of Risk to Boeing			
1A	Pump & Treat (P&T) with sewer discharge, Slug Injections into existing wells	3	This is conventional technology and the risk of uncontained release is relatively low. Is not ideal because of slug injections into existing wells. Although it is assumed that the wells will be siphoning, using existing infrastructure is inherently risky. Would protect Gage aquifer. This alternative would also target the 1000 ppb contour (due to site constraints), so the risk of contaminant mass leaving the site should be low. However, there is some risk associated with discharging site contaminants at 1 ppm to the sewer.
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	3	This is conventional technology and the risk of uncontained release is relatively low. Is not ideal because of slug injections into existing wells. Although it is assumed that the wells will be siphoning, using existing infrastructure is inherently risky. This alternative would target the 5000 ppb contour, but would also place wells to minimize off-site migration of groundwater within the 1000 ppb contour. There is some risk associated with discharging site contaminants at 1 ppm to the sewer.
1C	P&T with Reactive Biobarrier Slug injections into existing wells	1	This receives a low score because it does very little protect the Gage aquifer. This is less proven technology, and includes some possibility for fouling and/or poor hydraulic performance that would require additional work to rehabilitate. Also includes slug injections into existing wells. Although it is assumed that the wells will be siphoning, using existing infrastructure is inherently risky. This scenario targets the 1000 ppb contour at the site borders, but does not address the source area with the exception of some slug injections. This alternative has the advantage of avoiding above ground treatment, but will require use of double contained pipe and possibly leak detection systems.
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	4	Very low risk alternative. Treatment removes chemicals from reinjection process, therefore the possibility of release is reduced. Good protection of Gage aquifer. Only minor risk comes from using slug injections into existing wells. Although it is assumed that the wells will be siphoning, using existing infrastructure is inherently risky. This alternative would target remediation of the 5000 ppb contour in the B zone and the 1000 ppb contour in the C zone. This alternative would also include placement of extraction wells to minimize off-site migration of 1000 ppb water in both zones.
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	4	This alternative is very similar to alternative 1D, but it is more risky because of continuous injection into new existing wells.
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	3	This alternative is very similar to alternative 1D, but it is slightly more risky because of treatment is less risky than using double-contained piping. This alternative will require use of double contained pipe and possibly leak detection systems.
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	1	This alternative is similar to alternatives 1E and 1F. However, it receives a much lower score because impacted groundwater is being pumped into the existing infrastructure continuously, where the piping system is suspect and there is no dual-containment. Even with only new infrastructure, treatment is less risky than using double-contained piping and leak detection systems.
2A	P&T with sewer discharge	4	Very low risk alternative. This is a conventional technology and the risk of uncontained release is relatively low. Would protect Gage aquifer. This alternative would also target the 1000 ppb contour (due to site constraints), so the risk of contaminant mass leaving the site should be lower. However, there is some risk associated with discharging site contaminants at 1 ppm to the sewer.
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	4	This is a conventional technology and the risk of uncontained release is relatively low. Would protect Gage aquifer. This alternative would target remediation of the 5000 ppb contour in the B zone and the 1000 ppb contour in the C zone. This alternative would also include placement of extraction wells to minimize off-site migration of 1000 ppb water in both zones.

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Alternative	Name	Rating	Explanation
2C	P&T with Reactive Biobarrier	1	This receives a low score because it does very little protect the Gage aquifer. This is less proven technology, and includes some possibility for fouling and/or poor hydraulic performance that would require additional work to rehabilitate. Although it is assumed that the wells will be siphoning, using existing infrastructure is inherently risky. This scenario targets the 1000 ppb contour at the site borders, but does not address the source area. This alternative has the advantage of avoiding above ground treatment, but will require use of double contained pipe and possibly leak detection systems.
2D	P&T, Continuous injection of amended GW into new wells	4	This is a low risk alternative. Treatment removes chemicals from reinjection process, therefore the possibility of release is reduced. There is also no usage of existing infrastructure. Good protection of Gage aquifer. This alternative would target remediation of the 5000 ppb contour in the B zone and the 1000 ppb contour in the C zone. This alternative would also include placement of extraction wells to minimize off-site migration of 1000 ppb water in both zones.
2E	Pump (no treatment) Continuous injection of amended GW into new wells	3	Slightly more risky than alternative 2D, because treatment is less risky than using double-contained piping. However, there is no usage of existing infrastructure and its inherent risk. Good protection of Gage aquifer. This alternative would target remediation of the 5000 ppb contour in the B zone and the 1000 ppb contour in the C zone. This alternative would also include placement of extraction wells to minimize off-site migration of 1000 ppb water in both zones. This alternative will require use of double contained pipe and possibly leak detection systems.
3A	Slug Injection	1	Prior experience indicates that this is a risky option, even if it is assumed that only siphoning infrastructure will be used. Risks also involve need for additional remedial action (additional cost), as this is likely to be too ineffective. Provides much less protection of Gage aquifer.
Confidence in Technical Effectiveness			
1A	Pump & Treat (P&T) with sewer discharge, Slug Injections into existing wells	2	This alternative is effective in capturing contamination above 1000 ppb at the south boundary, however, the groundwater velocity increase in the source area is minor, and the slug injection of donor cover only a small area near the injection points before it is consumed. Little benefit is derived from the slug injection of donor due to the small area of influence.
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	4	Effective in treating the 5000 ppb contour in the B zone and the 1000 ppb contour in the C zone, and minimizing offsite migration of the 1000 ppb contour. This alternative provides good donor distribution in the source areas. The slug injection at existing wells is slightly more effective than 1A under this flow regime, due to the increased velocities.
1C	P&T with Reactive Biobarrier Slug injections into existing wells	1	This alternative can meet the objective of minimizing off-site migration of contaminants at high concentrations; however, this alternative would require long-term operations, since no enhanced treatment occurs within the source area. This alternative also is projected to increase the extent of the high concentrations by spreading the contamination laterally. This potential for lateral extension of the extent of contamination limits applicability of this alternative. There is no significant increase in effectiveness due to slug injections.
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	4	Effective in treating the 5000 ppb contour in the B zone and the 1000 ppb contour in the C zone, and minimizing offsite migration of the 1000 ppb contour. This alternative provides good donor distribution in the source areas. The slug injection at existing wells is slightly more effective than 1A under this flow regime, due to the increased velocities.
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	4	Very effective in treating the 5000 ppb contour in the B zone and the 1000 ppb contour in the C zone, and minimizing offsite migration of the 1000 ppb contour. This alternative provides good donor distribution in the source areas and meets the boundary containment objective. However, because the water will be treated, the recirculation of microbes will be minimal thereby reducing the overall effectiveness.

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Alternative	Name	Rating	Explanation
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	5	Effective in treating the 5000 ppb contour in the B zone and the 1000 ppb contour in the C zone, and minimizing offsite migration of the 1000 ppb contour. This alternative provides good donor distribution in the source areas. The slug injection at existing wells is slightly more effective than 1A under this flow regime, due to the increased velocities. In addition, since no treatment of the extracted water is done, the benefits of microbe recirculation are realized compared to 1E.
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	5	Most effective in treating the 5000 ppb contour in the B zone and the 1000 ppb contour in the C zone, and minimizing offsite migration of the 1000 ppb contour. This alternative provides good donor distribution in the source areas and meets the boundary containment objective. In addition, since no treatment of the extracted water is done, the benefits of microbe recirculation are realized compared to 1E.
2A	P&T with sewer discharge	2	Similar to 1A, except slightly reduced effectiveness as the source area does not undergo any enhanced treatment, only flushing at relatively low rates, which would result in extended remedy operation.
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	3	Similar to 1B except this alternative provides only moderate coverage of the source areas, as no slug injections are performed and areas under the buildings are not completely accessible, even with the use of angle drilling techniques to install the new wells. The containment objective can be met with this alternative.
2C	P&T with Reactive Biobarrier	1	This alternative can meet the objective of minimizing off-site migration of contaminants at high concentrations; however, this alternative would require long-term operations, since no enhanced treatment occurs within the source area. This alternative also is projected to increase the extent of the high concentrations by spreading the contamination laterally. This potential for lateral extension of the extent of contamination limits applicability of this alternative.
2D	P&T, Continuous injection of amended GW into new wells	3	Similar to 1D except this alternative provides only moderate coverage of the source areas, as no slug injections are performed and areas under the buildings are not completely accessible, even with the use of angle drilling techniques to install the new wells. The containment objective can be met with this alternative.
2E	Pump (no treatment) Continuous injection of amended GW into new wells	3	Similar to 1F except this alternative provides only moderate coverage of the source areas, as no slug injections are performed and areas under the buildings are not completely accessible, even with the use of angle drilling techniques to install the new wells. The containment objective can be met with this alternative.
3A	Slug Injection	1	Existing infrastructure has not shown thus far that it can accept flow at high enough rates under siphoning, and well performance may have degraded further since that testing due to molasses injections. Slug injections alone would be unlikely to generate sufficient groundwater velocity across the site to generate good converge of any electron donor, and therefore confidence in technical effectiveness is extremely low.
Implementability / Practicality			
1A	Pump & Treat (P&T) with sewer discharge, Slug Injections into existing wells	4	Relatively easy technology to implement. Required treatment would not be that complex, as discharge limits are not very low. Slug injections to existing wells may be more difficult. O&M requirements would be straightforward, but more time-intensive due to treatment, as the system may require GAC replacement or generate other waste streams that would require management. Regulatory approval would probably be relatively straightforward.
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	2	Mostly relatively easy technology to implement. Most difficult aspect of implementation would be arranging for fresh water source. Slug injections to existing wells will be more difficult. Fresh water will need to be reduced and amended, which would make this more complex than typical P&T. O&M requirements would be straightforward, but more time-intensive due to treatment, as the system may require GAC replacement or generate other waste streams that would require management. Regulatory approval would probably be relatively straightforward, with the exception of obtaining the fresh water. Slug injections to existing wells would be more difficult.

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Alternative	Name	Rating	Explanation
1C	P&T with Reactive Biobarrier Slug injections into existing wells	2	More difficult to implement, due to requirements for the biobarrier to be effective. Installation would be more complicated than other options. Would require all the components of P&T (on a smaller scale) in addition to the permeable biobarrier. Would require less-straightforward performance monitoring and hydraulic balancing to demonstrate results. Operation and maintenance would likely be less time-intensive but more difficult. Regulatory approval may be more difficult than other alternatives. Slug injections to existing wells would be more difficult.
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	2	P&T technology is easy to implement, but treatment necessary for conveyance without double contained piping would be very complex. Slug injections to existing wells may be more difficult. O&M requirements would be straightforward, but definitely time-intensive due to complex treatment process, and the system may require GAC replacement or generate other waste streams that may require management. Regulatory approval would probably a little less straightforward than P&T.
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	1	P&T technology is easy to implement, but treatment necessary for conveyance without double contained piping would be very complex. Continuous injection to existing wells would be difficult to implement effectively (would require larger level of controls to ensure siphoning flow). O&M requirements would be straightforward, but definitely time-intensive due to complex treatment process, and the system may require GAC replacement or generate other waste streams that would require management. Regulatory approval would probably a little less straightforward than P&T.
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	4	Relatively easy to implement. Amendment system would be simple. Double-contained piping is a little more difficult to implement, but is feasible. Slug injections to existing wells may be more difficult. O&M requirements would be straightforward. There would be no waste streams, but some chemical use (e.g. electron donor). Regulatory approval would probably a little less straightforward than P&T.
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	3	Relatively easy to implement. Amendment system would be simple. Double-contained piping is a little more difficult to implement, but is feasible. Continuous injection to existing wells would be slightly more difficult to implement safely (would require larger level of controls to ensure siphoning flow). O&M requirements would be straightforward. There would be no waste streams, but some chemical use (e.g. electron donor). Regulatory approval would probably a little less straightforward than P&T.
2A	P&T with sewer discharge	5	Easiest option to implement. P&T is proven technology, and sewer discharge would not require complex treatment processes. O&M requirements would be straightforward, but more time-intensive due to treatment, as the system may require GAC replacement or generate other waste streams that would require management. Regulatory approval would probably relatively straightforward. No use of existing infrastructure makes this more simple as well.
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	3	Mostly relatively easy technology to implement. Most difficult aspect of implementation would be arranging for fresh water source. Fresh water will need to be reduced and amended, which would make this more difficult than typical P&T. O&M requirements would be straightforward, but more time-intensive due to treatment, as the system may require GAC replacement or generate other waste streams that would require management. Regulatory approval would probably relatively straightforward, with the exception of obtaining the fresh water. No use of existing infrastructure makes this more simple.
2C	P&T with Reactive Biobarrier	3	More difficult to implement, due to requirements for the biobarrier to be effective. Installation would be more complicated than other options. Would require all the components of P&T (on a smaller scale) in addition to the permeable biobarrier. Would require less-straightforward performance monitoring and hydraulic balancing to demonstrate results. Operation and maintenance would likely be less time-intensive but more difficult. Regulatory approval may be more difficult than other alternatives.

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Alternative	Name	Rating	Explanation
2D	P&T, Continuous injection of amended GW into new wells	2	P&T technology is easy to implement, but treatment necessary for conveyance without double contained piping would be very complex. No use of existing infrastructure makes this slightly more simple. O&M requirements would be straightforward, but definitely time-intensive due to complex treatment process, and the system may require GAC replacement or generate other waste streams that would require management. Regulatory approval would probably a little less straightforward than P&T.
2E	Pump (no treatment) Continuous injection of amended GW into new wells	4	Relatively easy to implement. Amendment system would be simple. Double-contained piping is a little more difficult to implement, but is feasible. No use of existing infrastructure would make this more easier to operate as well. O&M requirements would be straightforward. There would be no waste streams, but some chemical use (e.g. electron donor). Regulatory approval would probably a little less straightforward than P&T.
3A	Slug Injection	2	Would be mostly easy to implement (no new infrastructure required), but would be difficult to implement without incurring risk or with any effectiveness. Operation would be difficult, as it would require careful field to minimize risk of further problems. Regulatory would be probably be difficult to obtain due to effectiveness concerns.
Minimization of Site Impact			
1A	Pump & Treat (P&T) with sewer discharge, Slug Injections into existing wells	3	Would require installation of only a few new extraction and injection wells, and associated piping and vaults, but footprint is less than other alternatives. Usage of existing infrastructure for slug injection lowers this score as repeated site visits will be necessary.
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	2	Would require installation of several new extraction and injection wells, and associated piping and vaults. Usage of existing infrastructure for slug injection lowers this score as repeated site visits will be necessary.
1C	P&T with Reactive Biobarrier Slug injections into existing wells	3	Installation of biobarrier would require fairly intrusive and disruptive site operations compared to other operations, but they would be limited to one area. Site disruptions would not be very flexible. Any maintenance on the system would also be below-ground, thus requiring further disruption. Would also require same new infrastructure as P&T, but on smaller scale.
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	2	Would require installation of several new extraction and injection wells, and associated piping and vaults. Usage of existing infrastructure for slug injection lowers this score as repeated site visits will be necessary.
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	1	Would require installation of several new extraction and injection wells, and associated piping and vaults, but not as many as some other alternatives. Usage of existing infrastructure for continuous injection increases site impact during construction as well.
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	2	Would require installation of new extraction and injection wells, and associated piping and vaults.
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	1	Would require installation of several new extraction and injection wells, and associated piping and vaults, but not as many as some other alternatives. Usage of existing infrastructure for continuous injection increases site impact during construction as well.
2A	P&T with sewer discharge	4	Would require installation of only a few extraction and injection wells, and associated piping and vaults.
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	2	Would require installation of several new extraction and injection wells, and associated piping and vaults.

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Alternative	Name	Rating	Explanation
2C	P&T with Reactive Biobarrier	3	Installation of biobarrier would require fairly intrusive and disruptive site operations compared to other operations, but they would be limited to one area. Site disruptions would not be very flexible. Any maintenance on the system would also be below-ground, thus requiring further disruption.
2D	P&T, Continuous injection of amended GW into new wells	2	Would require installation of several new extraction and injection wells, and associated piping and vaults.
2E	Pump (no treatment) Continuous injection of amended GW into new wells	2	Would require installation of several new extraction and injection wells, and associated piping and vaults, but not as many as some other alternatives.
3A	Slug Injection	5	Very little site disruption (no new infrastructure).
Minimization of Cost			
1A	Pump & Treat (P&T) with sewer discharge, Slug Injections into existing wells	1	PRELIMINARY EVALUATION: Although the cost of design and implementation will be relatively low compared to other alternatives, the overall cost of this alternative will be high, because the expected duration of O&M will be lengthy. The cost of this item is increased by the usage of existing infrastructure (testing, some additional controls used during slug injections, etc).
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	1	PRELIMINARY EVALUATION: The cost of design and implementation of this alternative should be comparable to others, as many of its components are similar to other alternatives (P&T, amendment injection). However, the usage of fresh water could potentially make this alternative very expensive. It will not have the same duration of O&M as a pure P&T alternative, but the fresh water cost could make this prohibitive. The cost of this item is increased more by the continuous usage of existing infrastructure (testing, additional controls at each well, more injectant, etc). This alternative also includes more wells than most of the other alternatives.
1C	P&T with Reactive Biobarrier Slug injections into existing wells	1	PRELIMINARY EVALUATION: The cost of design and implementation of a reactive biobarrier into the C-sand will likely be high. Because the alternative relies on containment and does not address the source, the expected duration of O&M will be lengthy. The costs of this item is also increased by the usage of existing infrastructure (testing, additional controls, etc).
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	2	PRELIMINARY EVALUATION: The implementation of this system should be similar to 1B, with the exception of the addition of a more complex treatment system and the subtraction of fresh water supply. Because the system will be treating down to lower effluent concentrations, it will be more expensive and will likely require benchscale or pilot testing to verify effectiveness. However, this will avoid the cost of dual contained piping on all injection lines. The cost of this item is increased by the usage of existing infrastructure (testing, some additional controls used during slug injections, etc). This alternative also includes more wells than most of the other alternatives.
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	3	PRELIMINARY EVALUATION: The implementation of this system should be similar to 1B (minus the fresh water supply), with the exception of the addition of a more complex treatment system and the subtraction of fresh water supply. Because the system will be treating down to lower effluent concentrations, it will be more expensive and will likely require benchscale or pilot testing to verify effectiveness. However, this will avoid the cost of dual contained piping on all injection lines. The cost of this item is increased more by the continuous usage of existing infrastructure (testing, additional controls at each well, more injectant, etc).
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	3	PRELIMINARY EVALUATION: This option is cheaper than 1D because it does not include any treatment, but it does include a large amount of new wells. There will be costs associated with new wells, dual-contained conveyance, and the amendment system, but those should be less than the other alternatives. The cost of this item is increased by the usage of existing infrastructure (testing, some additional controls used during slug injections, etc).

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Alternative	Name	Rating	Explanation
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	4	PRELIMINARY EVALUATION: This alternative will probably be cheaper than most others that includes new and existing infrastructure. There will be costs associated with new wells, dual-contained conveyance, and the amendment system, but those should be less than the other alternatives. The cost of this item is increased more by the continuous usage of existing infrastructure (testing, additional controls at each well, more injectant, etc).
2A	P&T with sewer discharge	1	PRELIMINARY EVALUATION: Although the cost of design and implementation will be relatively low compared to other alternatives, the overall cost of this alternative will be high, because the expected duration of O&M will be make this alternative lengthy.
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	1	PRELIMINARY EVALUATION: The cost of design and implementation of this alternative should be comparable to others, as many of its components are similar to other alternatives (P&T, amendment injection). However, the usage of fresh water could potentially make this alternative very expensive. It will not have the same duration of O&M as a pure P&T alternative, but the fresh water cost could make this prohibitive.
2C	P&T with Reactive Biobarrier	1	PRELIMINARY EVALUATION: The cost of design and implementation of a reactive biobarrier into the C-sand will likely be high. Because the alternative relies on containment and does not address the source, the expected duration of O&M will be lengthy.
2D	P&T, Continuous injection of amended GW into new wells	3	PRELIMINARY EVALUATION: The implementation of this system should be similar to 2B, with the exception of the addition of a more complex treatment system and the subtraction of fresh water supply. Because the system will be treating down to lower effluent concentrations, it will be more expensive and will likely require benchscale or pilot testing to verify effectiveness. However, this will avoid the cost of dual contained piping on all injection lines. The costs of this item is also increased more by the continuous usage of existing infrastructure (testing, additional controls, etc).
2E	Pump (no treatment) Continuous injection of amended GW into new wells	4	PRELIMINARY EVALUATION: This is most likely the cheapest option that includes new infrastructure only. There will be costs associated with new wells, dual-contained conveyance, and the amendment system, but those should be less than the other alternatives.
3A	Slug Injection	4	PRELIMINARY EVALUATION: Cost of doing slug injections would be relatively low compared to other alternatives (no new infrastructure). However, additional costs would be incurred: additional hydraulic and electron donor testing and any costs resulting of technical ineffectiveness. There would be no opportunities for cost savings (as this alternative is unlikely to overshoot remedial goals).
Flexibility			
1A	Pump & Treat (P&T) with sewer discharge, Slug Injections into existing wells	5	Centralized treatment system would not be that difficult to expand, due to simple processes. Slug injections offer ability to do some limited in-situ treatment of certain areas. Could design system such that it would be able to expand conveyance and extraction portions incrementally as desired.
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	4	Centralized treatment system would not be that difficult to expand, due to simple treatment system. Slug injections offer ability to do some limited in-situ treatment of certain areas. Could design system such that it would be able to expand conveyance/extraction/injection portions incrementally as desired. However, it may be difficult to significantly change the amount of fresh water that would be available.
1C	P&T with Reactive Biobarrier Slug injections into existing wells	2	Reactive biobarrier would be not very flexible. P&T portion would be almost as flexible as other P&T systems with sewer discharge. However, as the treatment system would be sized for relatively small extraction volumes, it may be slightly smaller to expand. It would still be relatively easy to install more capacity in parallel to any previously installed system. Slug injections offer ability to do some limited in-situ treatment of certain areas.
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	2	Centralized treatment system would be slightly more difficult to expand, due to more complex treatment processes. Slug injections offer ability to do more limited in-situ treatment of certain areas. Could design system such that it would be able to expand conveyance/extraction/injection portions incrementally as desired.

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Alternative	Name	Rating	Explanation
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	2	Centralized treatment system would be slightly more difficult to expand, due to more complex treatment processes. Could design system such that it would be able to expand conveyance/extraction/injection portions incrementally as desired.
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	5	Centralized amendment system would be easy to expand, due to very simple processes. Slug injections offer ability to do some limited in-situ treatment of certain areas. Could design system such that it would be able to expand conveyance/extraction/injection portions incrementally as desired.
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	5	Centralized amendment system would be easy to expand, due to very simple processes. Could design system such that it would be able to expand conveyance/extraction/injection system incrementally as desired.
2A	P&T with sewer discharge	5	Centralized treatment system would not be that difficult to expand, due to simple processes. Could design system such that it would be able to expand conveyance and extraction portions incrementally as desired.
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	4	Centralized treatment system would not be that difficult to expand, due to simple treatment system. Could design system such that it would be able to expand conveyance/extraction/injection portions incrementally as desired. However, it may be difficult to significantly change the amount of fresh water that would be available.
2C	P&T with Reactive Biobarrier	2	Reactive biobarrier would be not very flexible. P&T portion would be almost as flexible as other P&T systems with sewer discharge. However, as the treatment system would be sized for relatively small extraction volumes, it may be slightly smaller to expand. It would still be relatively easy to install more capacity in parallel to any previously installed system.
2D	P&T, Continuous injection of amended GW into new wells	2	Centralized treatment system would be slightly more difficult to expand, due to more complex treatment processes. Could design system such that it would be able to expand conveyance/extraction/injection portions incrementally as desired.
2E	Pump (no treatment) Continuous injection of amended GW into new wells	5	Centralized amendment system would be easy to expand, due to very simple processes. Could design system such that it would be able to expand conveyance/extraction/injection system incrementally as desired.
3A	Slug Injection	1	Remedial approach is inherently constrained by existing infrastructure.
Expedited Implementation			
1A	Pump & Treat (P&T) with sewer discharge, Slug Injections into existing wells	5	Design and sizing of the system would be relatively easy, given the less-stringent discharge requirements for the sewer. Well and conveyance piping design and installation would be comparable to other similar alternatives.
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	4	Design and sizing of the system would be relatively easy, given the less-stringent discharge requirements for the sewer. Well and conveyance piping design and installation would be comparable to other similar alternatives, except for the additional time required to tie in existing infrastructure and the fresh water source.
1C	P&T with Reactive Biobarrier Slug injections into existing wells	2	Design and sizing of the treatment system would be more complex than many of the other alternatives, because of the stringent treatment requirements without double-contained piping. This complex treatment process may also require additional long-lead treatment equipment. Well and conveyance piping design and installation would be comparable to other similar alternatives. Installation of the P&T portion would be fairly-straightforward from a scheduling standpoint, but installation of the barrier would likely take more time.

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Alternative	Name	Rating	Explanation
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	3	Design and sizing of the treatment system would be more complex than many of the other alternatives, because of the stringent treatment requirements without double-contained piping. This step may require benchscale or pilot testing, which could delay implementation. This complex treatment process may also require additional long-lead treatment equipment. Well and conveyance piping design and installation would be comparable to other similar alternatives. Installation of the P&T portion would be fairly-straightforward from a scheduling standpoint, but installation of the barrier would likely take more time.
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	3	Design and sizing of the treatment system would be more complex than many of the other alternatives, because of the stringent treatment requirements without double-contained piping. This step may require benchscale or pilot testing, which could delay implementation. This complex treatment process may also require additional long-lead treatment equipment. Well and conveyance piping design and installation would be comparable to other similar alternatives, except for the additional time required to tie in existing infrastructure. Installation of the P&T portion would be fairly-straightforward from a scheduling standpoint.
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	5	Design and sizing of the amendment system would be relatively simple. Well and conveyance piping design and installation would be comparable to other similar alternatives. Installation of the system would be fairly-straightforward from a scheduling standpoint.
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	4	Design and sizing of the amendment system would be relatively simple. Well and conveyance piping design and installation would be comparable to other similar alternatives, except for the additional time required to tie in existing infrastructure. Installation of the system would be fairly-straightforward from a scheduling standpoint.
2A	P&T with sewer discharge	5	Design and sizing of the system would be relatively easy, given the less-stringent discharge requirements for the sewer. Well and conveyance piping design and installation would be comparable to other similar alternatives.
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	4	Design and sizing of the system would be relatively easy, given the less-stringent discharge requirements for the sewer. Well and conveyance piping design and installation would be comparable to other similar alternatives, except for the additional time required to tie in existing infrastructure and the fresh water source.
2C	P&T with Reactive Biobarrier	2	Design and sizing of the treatment system would be more complex than many of the other alternatives, because of the stringent treatment requirements without double-contained piping. This complex treatment process may also require additional long-lead treatment equipment. Well and conveyance piping design and installation would be comparable to other similar alternatives. Installation of the P&T portion would be fairly-straightforward from a scheduling standpoint, but installation of the barrier would likely take more time.
2D	P&T, Continuous injection of amended GW into new wells	4	Design and sizing of the treatment system would be more complex than many of the other alternatives, because of the stringent treatment requirements without double-contained piping. This step may require benchscale or pilot testing, which could delay implementation. This complex treatment process may also require additional long-lead treatment equipment. Well and conveyance piping design and installation would be comparable to other similar alternatives. Installation of the P&T portion would be fairly-straightforward from a scheduling standpoint, but installation of the barrier would likely take more time.
2E	Pump (no treatment) Continuous injection of amended GW into new wells	5	Design and sizing of the amendment system would be relatively simple. Well and conveyance piping design and installation would be comparable to other similar alternatives, except for the additional time required to tie in existing infrastructure. Installation of the system would be fairly-straightforward from a scheduling standpoint.
3A	Slug Injection	4	Would be very quick to implement, as it requires no new infrastructure. However, it would be necessary to do a significant amount of testing before using existing infrastructure.

Table 4
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Explanation of Remedial Technology Alternatives Evaluation

Alternative	Name	Rating	Explanation
Expedited Cleanup			
1A	Pump & Treat (P&T) with sewer discharge, Slug Injections into existing wells	2	It is anticipated that P&T operation would be necessary for some time before site cleanup was completed.
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	4	It is anticipated that P&T operation would be necessary for some time before site cleanup was completed. However, the simultaneous usage of in-situ treatment would expedite treatment. However, because existing in-situ populations are not recirculated, this alternative is not ideal.
1C	P&T with Reactive Biobarrier Slug injections into existing wells	1	It is anticipated that a biobarrier system would remediate the site at a slow pace, as it would not address the source.
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	4	Bioremediation with sufficient coverage would remediate the site much faster than alternatives with ex-situ treatment. However, because existing in-situ populations are not recirculated, this alternative is not ideal.
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	4	Bioremediation with sufficient coverage would remediate the site much faster than alternatives with ex-situ treatment. However, because existing in-situ populations are not recirculated, this alternative is not ideal.
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	5	Bioremediation with sufficient coverage would remediate the site much faster than alternatives with ex-situ treatment.
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	5	Bioremediation with sufficient coverage would remediate the site much faster than alternatives with ex-situ treatment.
2A	P&T with sewer discharge	2	Design and sizing of the system would be relatively easy, given the less-stringent discharge requirements for the sewer. Well and conveyance piping design and installation would be comparable to other similar alternatives. Installation of a P&T system would be fairly-straightforward from a scheduling standpoint. However, it is not anticipated that P&T operation would be necessary for some time before site cleanup was completed.
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	4	It is anticipated that P&T operation would be necessary for some time before site cleanup was completed. However, the simultaneous usage of in-situ treatment would expedite treatment. However, because existing in-situ populations are not recirculated, this alternative is not ideal.
2C	P&T with Reactive Biobarrier	1	It is anticipated that a biobarrier system would remediate the site at a slow pace, as it would not address the source.
2D	P&T, Continuous injection of amended GW into new wells	4	Bioremediation with sufficient coverage would remediate the site much faster than alternatives with ex-situ treatment. However, because existing in-situ populations are not recirculated, this alternative is not ideal.
2E	Pump (no treatment) Continuous injection of amended GW into new wells	5	Bioremediation with sufficient coverage would remediate the site much faster than alternatives with ex-situ treatment.
3A	Slug Injection	1	Existing infrastructure has not shown thus far that it can accept flow at high enough rates under siphoning, and well performance may have degraded further since that testing due to molasses injections. Slug injections would be unlikely to generate sufficient groundwater velocity across the site to generate good converge of any electron donor, and it is anticipated that cleanup using this alternative would be extremely slow.

Table 4
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Explanation of Remedial Technology Alternatives Evaluation

Alternative	Name	Rating	Explanation
Permanence			
1A	Pump & Treat (P&T) with sewer discharge, Slug Injections into existing wells	1	It is anticipated that P&T technologies would not lead to the same stable site conditions as in-situ technologies. Usage of P&T technology would incur waste streams, as treatment technology used for this alternative would likely be non-destructive (GAC, etc) due to cost reasons. P&T alternatives also have the ability to pull off-site contamination onto the site. Slug injections could help with pockets of residual contamination.
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	3	Usage of P&T and in-situ technologies would enhance convergence to stable site conditions. May ex-situ treatment technologies would incur waste streams. Usage of P&T technology would incur waste streams, as treatment technology used for this alternative would likely be non-destructive (GAC, etc) due to cost reasons. P&T alternatives also have the ability to pull off-site contamination onto the site. Slug injections could help with pockets of residual contamination.
1C	P&T with Reactive Biobarrier Slug injections into existing wells	1	This alternative would have similar abilities with regards to permanence to a P&T-based system, as they would both be constrained by groundwater flow. However, the biobarrier would destroy site contaminants. Slug injections could help with pockets of residual contamination.
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	4	Usage of P&T and in-situ technologies would enhance convergence to stable site conditions. May ex-situ treatment technologies would incur waste streams. However, treatment requirements would be so stringent that non-destructive technologies (e.g. GAC) may not be solely sufficient to treat extracted groundwater, and destructive technologies (e.g. advanced oxidation) might be necessary as well. P&T alternatives also have the ability to pull off-site contamination onto the site. Slug injections could help with pockets of residual contamination.
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	4	Usage of P&T and in-situ technologies would enhance convergence to stable site conditions. May ex-situ treatment technologies would incur waste streams. However, treatment requirements would be so stringent that non-destructive technologies (e.g. GAC) may not be solely sufficient to treat extracted groundwater, and destructive technologies (e.g. advanced oxidation) might be necessary as well. P&T alternatives also have the ability to pull off-site contamination onto the site.
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	5	In-situ treatment would be destructive and would be more likely to lead to stable site conditions. Slug injections could help with pockets of residual contamination.
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	5	In-situ treatment would be destructive and would be more likely to lead to stable site conditions.
2A	P&T with sewer discharge	1	It is anticipated that P&T technologies would not lead to the same stable site conditions as in-situ technologies. Usage of P&T technology would incur waste streams, as treatment technology used for this alternative would likely be non-destructive (GAC, etc) due to cost reasons. P&T alternatives also have the ability to pull off-site contamination onto the site.
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	3	Usage of P&T and in-situ technologies would enhance convergence to stable site conditions. May ex-situ treatment technologies would incur waste streams. Usage of P&T technology would incur waste streams, as treatment technology used for this alternative would likely be non-destructive (GAC, etc) due to cost reasons. P&T alternatives also have the ability to pull off-site contamination onto the site. Slug injections could help with pockets of residual contamination.
2C	P&T with Reactive Biobarrier	1	This alternative would have similar abilities with regards to permanence to a P&T-based system, as they would both be constrained by groundwater flow. However, the biobarrier would destroy site contaminants.

Table 4
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Explanation of Remedial Technology Alternatives Evaluation

Alternative	Name	Rating	Explanation
2D	P&T, Continuous injection of amended GW into new wells	4	Usage of P&T and in-situ technologies would enhance convergence to stable site conditions. May ex-situ treatment technologies would incur waste streams. However, treatment requirements would be so stringent that non-destructive technologies (e.g. GAC) may not be solely sufficient to treat extracted groundwater, and destructive technologies (e.g. advanced oxidation) might be necessary as well. P&T alternatives also have the ability to pull off-site contamination onto the site. Slug injections could help with pockets of residual contamination.
2E	Pump (no treatment) Continuous injection of amended GW into new wells	5	In-situ treatment would be destructive and would be more likely to lead to stable site conditions.
3A	Slug Injection	1	Existing infrastructure has not shown thus far that it can accept flow at high enough rates under siphoning, and well performance may have degraded further since that testing due to molasses injections. Slug injections would be unlikely to generate sufficient groundwater velocity across the site to generate good converge of any electron donor, and it is anticipated that cleanup using this alternative will not lead to very stable site conditions. However, bioremediation is a more permanent treatment strategy than P&T and there would be no adverse with respect surrounding plumes.
Minimization of Need for Studies			
1A	Pump & Treat (P&T) with sewer discharge, Slug Injections into existing wells	2	Usage of existing infrastructure will require hydraulic testing to confirm it is still usable, but this is less important for slug injections. Electron donor treatability testing will be necessary for any slug injections. Aquifer performance tests will also be necessary to determine well configuration.
1B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells, Slug injections into existing wells	2	Usage of existing infrastructure will require hydraulic testing to confirm it is still usable. Electron donor treatability testing will be necessary for any slug and continuous injections. Aquifer performance tests will also be necessary to determine well configuration.
1C	P&T with Reactive Biobarrier Slug injections into existing wells	2	Usage of existing infrastructure will require hydraulic testing to confirm it is still usable, but this is less important for slug injections. Electron donor treatability testing will be necessary for any slug injections. Aquifer performance tests will also be necessary to determine well configuration. More intricate geological investigation may be necessary prior to barrier installation.
1D	P&T, Continuous injection of amended GW into new wells Slug injections into existing wells	1	Usage of complex treatment processes may require benchscale and/or pilot studies prior to full-scale implementation. Usage of existing infrastructure will require hydraulic testing to confirm it is still usable, but this is less important for slug injections. Electron donor treatability testing will be necessary for any slug and continuous injections. Aquifer performance tests will also be necessary to determine well configuration.
1E	P&T, Continuous injection of amended and treated GW into new and existing wells	1	Usage of complex treatment processes may require benchscale and/or pilot studies prior to full-scale implementation. Usage of existing infrastructure will require hydraulic testing to confirm it is still usable. Electron donor treatability testing will be necessary for any slug and continuous injections. Aquifer performance tests will also be necessary to determine well configuration.
1F	Pump (no treatment) Continuous injection of amended GW into new wells Slug injections into existing wells	2	Usage of existing infrastructure will require hydraulic testing to confirm it is still usable, but this is less important for slug injections. Electron donor treatability testing will be necessary for any slug and continuous injections. Aquifer performance tests will also be necessary to determine well configuration.
1G	Pump (no treatment), Continuous injection of amended GW into new and existing wells	2	Usage of existing infrastructure will require hydraulic testing to confirm it is still usable. Electron donor treatability testing will be necessary for any slug and continuous injections. Aquifer performance tests will also be necessary to determine well configuration.
2A	P&T with sewer discharge	3	No testing of existing infrastructure will be necessary. Electron donor treatability testing will be necessary for any slug injections. Aquifer performance tests will also be necessary to determine well configuration.

Table 4
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Explanation of Remedial Technology Alternatives Evaluation

Alternative	Name	Rating	Explanation
2B	P&T with sewer discharge, Continuous injection of amended fresh water into new wells	3	No testing of existing infrastructure will be necessary. Electron donor treatability testing will be necessary for any continuous injections. Aquifer performance tests will also be necessary to determine well configuration.
2C	P&T with Reactive Biobarrier	3	No testing of existing infrastructure will be necessary. Aquifer performance tests will also be necessary to determine well configuration. More intricate geological investigation may be necessary prior to barrier installation.
2D	P&T, Continuous injection of amended GW into new wells	2	Usage of complex treatment processes may require benchscale and/or pilot studies prior to full-scale implementation. No testing of existing infrastructure will be necessary. Electron donor treatability testing will be necessary for any continuous injections. Aquifer performance tests will also be necessary to determine well configuration.
2E	Pump (no treatment) Continuous injection of amended GW into new wells	3	No testing of existing infrastructure will be necessary. Electron donor treatability testing will be necessary for any continuous injections. Aquifer performance tests will also be necessary to determine well configuration.
3A	Slug Injection	2	Usage of existing infrastructure will require hydraulic testing to confirm it is still usable. Electron donor treatability testing will also be necessary to determine which electron donors would be best suited for the site. However, all studies related to installation of new infrastructure (e.g. Aquifer Performance Tests) would not be necessary.

Table 5
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Explanation of Phased Implementation Alternatives Evaluation

Criterion	Evaluation Notes
Minimization of Risk to Boeing	Preference is given to any remedial action alternative that addresses the C aquifer first, as protection of the C aquifer is more protective of the Gage aquifer. Preference is given to addressing the Sunrider property first, as it is further downgradient. However, some risk is removed by addressing Lot 8 first, as infrastructure that is already present there and is located not underneath the building will allow for pilot testing of the selected alternative. Additionally, use of existing infrastructure in Lot 8 is much less risky, especially for infrastructure that does not cross under buildings.
Confidence in Technical Effectiveness	All phased implementation alternatives were scored lower compared to "no phasing" alternative because they would not address large areas and may delay the beginning of remediation in other areas. Similarly, alternatives that focused on more than one area or zone (e.g. starting on Lot 8 B and C sands as opposed to starting on Lot 8, B sand only) were scored higher because they addressed larger areas. However, the phased alternatives were scored based on their relative benefit. For example, the Sunrider alternative was scored higher than Lot 8 because it is downgradient and would help minimize impacts downgradient of the site. Similarly, C-Sand alternatives were generally scored higher since they would reduce potential impacts Gage better than B-Sand alternatives. Importance was also given phased alternatives that would address the most contaminant mass.
Implementability / Practicality	Phased implementation was generally scored lower overall because it will add more complexity to planning and implementation. Phased implementation on Sunrider property was scored lower because of potential access restrictions and logistical issues (these issues may change in the future, depending on Sunrider's activities). However, phased implementation in Lot 8 was scored high because some existing infrastructure there is ready for use.
Minimization of Site Impact	Phased implementation was scored worse in this category because it will likely prolong site construction and adverse impacts to site tenants/owners. This is especially true if construction targets one aquifer in an area during the first phase and the other aquifer in the second phase.

Table 5
Former C-6 Facility
Focused Feasibility Study - Groundwater Remediation
Explanation of Phased Implementation Alternatives Evaluation

Criterion	Evaluation Notes
Minimization of Cost	Phased implementation was scored worse in this category because it will prolong the design and implementation process, rather than taking advantage of economies of scale. Please note that it is assumed that sufficient data and design work will be accomplished such that the lessons learned during phased implementation will not be significant, and no additional significant costs will be incurred as a result.
Flexibility	Phased implementation was scored higher in this category, as it offers greater ability to adjust remedial objectives during construction.
Expedited Implementation	Phased implementation was scored higher in this category, as it will accelerate the start of implementation at the site. Some studies (such as Aquifer Performance Test and electron donor treatability tests) and some aspects of implementation (such as permitting) will not be reduced. However, there may be some time savings in evaluation of existing infrastructure (if applicable), design tasks, and construction. Phased implementation in Lot 8 was also scored higher, as it will not require the same amount of coordination as phased implementation on the Sunrider property, and some existing infrastructure there is ready for use.
Expedited Cleanup	Phased implementation was generally scored lower in this category, as it will delay implementation of full-scale site implementation and remediation. However, Alternatives that address areas with high concentrations first were also scored higher, as they are focused on the source areas. Some amount of concurrent operation is assumed, e.g. the first phase of implementation can occur during the second phase of design and permitting.
Permanence	It is assumed that full-scale implementation will eventually occur in every scenario, and as the permanence criterion is only concerned long-term effects, there was no difference in scoring here.
Minimization of Need for Studies	It is assumed that full-scale implementation will eventually occur in every scenario, and that the need for additional studies will not be alleviated by phased implementation. Therefore, there was no difference in scoring here. However, the difference in existing infrastructure testing requirements between Lot 8 and Sunrider do impact the ratings for the Expedited Implementation criterion.

Appendix A

Brief Evaluation of Existing Amendment Wells

As part of determining suitable alternatives for the FS evaluation, CDM utilized prior hydraulic and electron donor injection testing performed in the former Building 2 area and the Lot 8 area to evaluate which existing wells could be included in any of the alternatives. Most of this effort was completed during the paper evaluation that is documented in the Pre-Remediation Implementation Workplan (CDM, August 7, 2006). During that paper evaluation, CDM evaluated the prior testing data to determine which wells would require additional hydraulic testing before use. Due to the prior surface leakage at the site, conservative criteria were utilized for the paper evaluation as listed below:

- wells that siphoned every time they were tested and were in good condition at the end of the first round of testing were considered acceptable without additional testing;
- wells that leaked or were taken out of service by prior consultants were considered unusable; and
- all other wells may be usable during site remediation (for e.g. all of the Lot 8 wells), but would require hydraulic testing before use.

After this analysis, there were only 17 wells (all in the Sunrider property) that were considered acceptable without further testing. Eighteen wells in the Sunrider property were found to be unsuitable for further use, and the remaining 297 wells (134 in the Sunrider property and 163 in Lot 8) required some amount of testing. However, for the purposes of this FS, it is necessary to make reasonable judgment of which of these 297 wells should be considered usable and which should not, so that the evaluation can determine if these wells should be included or not. Future hydraulic testing may still be necessary if some or all of these wells are used, especially in the Sunrider property.

A.1 Evaluation of Sunrider Property Amendment Wells

For the Sunrider property where previous extensive previous testing data exists, CDM performed a brief second evaluation of the 134 wells, to split the wells into two groups:

- First group of wells that will probably be useful, and therefore should be considered in the alternatives evaluation; and
- Second group of wells that may or may not be useful, but should not be considered in the evaluation of the alternatives being studied in this FS.

These wells were split according to the following criteria:

- Only a small subset of wells was considered for the first group. This included 82 wells that failed to siphon only once during the previous tests. Three wells that siphoned every time during testing, but were not in good condition at the end of each test or only accepted molasses injection at very low rates were also considered.
- The second criterion centered on the condition of the well at the end of prior testing. To be considered acceptable based on this criterion, each of the 85 wells had to be in good condition during the water flush at the end of the testing. If a well recovered from the molasses injection and siphoned during the water flush (e.g. exhibited a wellhead pressure less or equal to 1.5 psig), or exhibited siphoning following the termination of the molasses injection, it was placed in the first group of wells, even if there were signs of slowed flow during the molasses injection.
- The final criterion only applied to one well. Of the several wells that were inspected for siphoning only twice but failed once, it was kept in the second group of wells even though it exhibited some favorable conditions following the water flush. It was kept in the second group because it accepted very little flow, and observed flow rate is the second most important indicator of future potential for success.

Application of the above criteria provided 70 wells that were assumed to be usable, just for the purposes of this FS. The remaining 64 were assumed to be unusable, even though they may be tested at a later stage. Therefore, these 70 wells and the 17 wells that performed very well during the first phase of testing totaled to 87 wells in Sunrider property that were considered usable for the purposes of the FS.

A.2 Evaluation of Lot 8 Amendment Wells

Post-installation water injection tests were conducted on 19 of the 163 wells in Lot 8 area by Haley & Aldrich in 2004 and 2005. Since all the wells in Lot 8 were installed using Hollow-Stem Auger (HSA) techniques, CDM looked at the amount of HSA wells in Sunrider that were retained for the purposes of FS based on the criteria used in Section A.1 above. The amount of HSA wells retained varied from approximately 66% to 75% of the total HSA wells in Sunrider property. CDM then assumed for the purposes of the FS that a similar percentage of the HSA wells in Lot 8 area would be useable. A conservative estimate using the lower end of that range (66%) resulted in a total of approximately 108 wells in Lot 8 that were considered usable for the purposes of the FS. It should be noted that the Lot 8 wells were constructed with more stringent quality controls (as indicated by BRC) and are likely usable without further testing, especially those which are outside the building footprint.

Appendix B

Preliminary Groundwater Modeling

B.1 Modeling Limitations and Assumptions

This evaluation should be considered preliminary in nature, since proposed aquifer performance tests to refine estimates of hydraulic properties at the site have not yet been completed. These alternatives have not been optimized, since significant uncertainties on the hydraulic properties exist especially for the C-Sand. Extensive characterization of contaminant distributions and water levels has been conducted at the Site. Several hydraulic tests have also been conducted in the B-Sand, including slug tests and tracer tests that support current estimates of hydraulic characteristics in this zone (Arcadis, 2002, Document 3145). Injection testing has also been conducted at the extensive network of injection wells at the site. Several recent slug tests have been conducted in the C-Sand and are considered in this analysis. The site conceptual model, as documented in cross-sections recently updated by Rubicon (August 2006), is also considered.

The model used to represent the Site is very simple, assuming uniform characteristics in each aquifer and has been updated to incorporate the following changes:

- Hydraulic properties in the C-Sand have been changed based on slug tests conducted by Tait Environmental Management in August 2006 at the Site. A value of 20 ft/day is now used.
- Based on the updated site cross-sections, the B-Sand and C-Sand appear to be in hydraulic communication in the Lot 8 area, where the B-C aquitard is absent.

Hydraulic conductivity values in B-Sand have been estimated using slug tests, multi-well aquifer tests, and tracer tests. A wide range in values has been reported from 10 to 145 ft/day. Slug tests and tracer tests lie at the lower end of this range (< 20 ft/day), while the multi-well aquifer tests indicate the higher values (70 to 145 ft/day). CDM was not able to locate any detailed data (raw data, plots) for the aquifer tests in the Portal to review and assess their reliability. As a result, the tracer test data (Aracdis G&M, 2003) are the most likely to provide reliable estimates of hydraulic conductivity for B-Sand which was assumed to be 20 ft/day. The hydraulic properties of the B-C Aquitard were assumed to be similar to clay, with a vertical hydraulic conductivity of 0.009 ft/day. Hydraulic gradients are imposed on the model using boundary conditions at the upgradient and downgradient model extents. These boundaries are at a sufficient distance to minimize the impact on the relative comparison of alternatives. These boundaries will be moved to a greater distance from the Site for the final design analysis. Aquifer performance tests in both the B-Sand and C-Sand are currently planned that will place a higher magnitude stress on each of the zones and allow more reliable estimates of hydraulic characteristics of both aquifers and the confining unit. The Site model will be updated and refined when these data are available.

The extent of delivery of ISEB fluids assumes that an average concentration of 3,000 milligrams per liter (mg/L) of an unspecified, yet to be selected, electron donor compound is injected into the treatment wells. This average may be reached by injecting higher concentrations for a portion of the time to avoid biofouling of the wells. Concentrations of donor compound at a minimum of 300 mg/L are assumed to be effective in facilitating degradation. A half-life of 30 days is assumed for evaluating the extent of the delivery. The ISEB fluids are assumed to travel without significant adsorption on the aquifer matrix at the concentrations involved. These assumptions will be updated when the treatability testing is completed and a donor compound is selected.

It should be also noted that the locations of the proposed extraction and treatment wells are preliminary and approximate and the final locations will be dependant on site and access restrictions and locations of underground utilities.

B.2 Summary of Results

The following table summarizes the new wells and flow rates for the modeled alternatives. The alternative descriptions focus on the modeling aspects and do not address differences in elements such as necessity for above ground treatment.

Alternative Description (Modeling-Based)	B-Sand		C-Sand		Modeled System Flow (gpm)
	New Injection Wells	New Extraction Wells	New Injection Wells	New Extraction Wells	
Alternative 1A - Boundary containment with extraction wells with ISEB using periodic slug injections at existing useable treatment wells	None	3	None	3	30
Alternatives 1B/1D/1F – Boundary containment with ISEB using continuous injection at new injection wells and periodic slug injections at existing useable wells	14	14	13	13	270

Alternative Description (Modeling-Based)	B-Sand		C-Sand		Modeled System Flow (gpm)
	New Injection Wells	New Extraction Wells	New Injection Wells	New Extraction Wells	
Alternatives 1E/1G – Boundary containment with ISEB using continuous injection at new and existing useable injection wells	7	13	11	13	260
Alternative 2A – Boundary containment with no reinjection.	None	3	None	3	30
Alternative 2C – Reactive bio-barrier for containment	6	6	5	5	110
Alternatives 2B/2D/2E – Boundary containment combined with ISEB at new injection wells	14	14	13	13	270

As indicated in the technical memorandum Alternative 3A (Slug injection of donor into existing assumed useable wells) was not evaluated in detail in the model, since earlier evaluations have shown it to be not effective. This alternative consists of periodic injection of donor compound at existing injection wells, relying on the low velocity groundwater to distribute the donor compound to downgradient areas. Prior evaluations of this alternative have indicated that groundwater velocities are less than 30 feet/year. The donor compound does not impact a significant area away from the injection points.

For the same reason, Alternative 1C (pump and treat with reactive biobarrier with slug injection into existing assumed useable wells) was not modeled as this is similar to Alternative 2C without slug injection.

B.3 Discussion of Results

B.3.1 Alternative 1A- Boundary containment with extraction wells with ISEB using periodic slug injections at existing useable treatment wells

This alternative consists of boundary containment to minimize migration of contaminant concentrations greater than 1,000 µg/L off the site, combined with periodic slug injections within the source areas. The periodic injection of donor compound would occur at a total of approximately 195 existing injection wells that are useable (estimated to be 87 total wells in Sunrider property and approximately 108 wells in Lot 8). The containment pumping will increase groundwater velocities and increase the area that is impacted by the donor compound before it degrades below effective concentrations. An extensive network of injection wells is currently in place at the Site, including under the building foundations. Available testing information on these existing injection wells was used to assess those wells which are likely to be useable (See Appendix A). Only those wells that are believed to be capable of injecting fluids at reasonable rates and pressures, or were constructed with larger diameter casing and are likely to be productive were assumed to be available for use in the treatment system. These useable existing injection wells are the same in each alternative that includes existing wells.

This alternative was simulated by evaluating a single cycle of slug injection at for only a subset of the existing injection wells, and steady-state pumping of the capture wells at the southern property boundary. The maximum extent of concentrations of donor compound exceeding 300 mg/L was plotted to assess the effectiveness of this alternative. Figures 1 through 4 show the location of treatment and recovery wells in each aquifer zone. Figures 5 and 6 show the potentiometric surface modeled for this alternative. Figures 7 and 8 show the extent of source area donor concentrations greater than 300 mg/L for the B and C-Sands. This alternative is effective in capturing contamination at the south boundary, however, the groundwater velocity increase in the source area is minor, and the slug injection of donor cover only a small area near the injection points before it is consumed. Little benefit is derived from the slug injection of donor due to the small area of influence.

B.3.2 Alternatives 1B/1D/1F – Boundary containment with ISEB using continuous injection at new injection wells and periodic slug injections at existing useable wells

This alternative consists of boundary containment to minimize migration of contaminant concentrations greater than 1,000 µg/L off of the site, combined with periodic slug injections within the source areas, and continuous injection at new wells. The periodic injection of donor compound would occur at existing injection wells that are useable. The new injection wells would include angle wells drilled beneath buildings that are operated at higher injection rates in order to increase groundwater velocities and allow greater spread of the donor compound before it is consumed. This alternative was

simulated using a single injection cycle at the existing wells and continuous injection at the new wells to approximate the donor distribution. Figures 9 through 12 show the location of extraction and treatment wells in the B and C sands. Figure 13 and 14 show the modeled potentiometric surface, while Figures 15 and 16 show the donor distribution. The slug injection at existing wells is slightly more effective under this flow regime, due to the increased velocities, however, periodic slug injections is anticipated to be of limited utility (See Alternatives 2D and 2E for the alternatives that do not include the slug injections). This alternative provides good donor distribution in the source areas.

B.3.2 Alternatives 1E/1G – Boundary containment with ISEB using continuous injection at new and existing useable injection wells

This alternative consists of boundary containment to minimize migration of contaminant concentrations greater than 1,000 µg/L off the site, combined with continuous injection at new wells and existing useable injection wells. Figures 17 through 20 show the location of extraction and treatment wells for this alternative. Figures 21 and 22 show the modeled potentiometric surface, while Figures 23 and 24 show the modeled donor distribution. This alternative provides good donor distribution in the source areas and meets the boundary containment objective.

B.3.4 Alternative 2A –Boundary containment with no reinjection

This alternative uses wells in the B and C sands at the southern site boundary to minimize migration of contaminant concentrations greater than 1,000 µg/L off of the site. No reinjection of donor compound occurs under this alternative. The simulation results indicate that capture of the target areas can be accomplished using 3 wells in the B-Sand and 3 wells in the C-Sand, each pumping at 5 gpm, or a total of 30 gpm. This water will be treated, if necessary, and discharged. Since the source area does not undergo any enhanced treatment, only flushing at relatively low rates, this alternative would operate for a long period of time. Figures 25 and 26 show the location of the extraction wells in the B and C sands, while Figures 27 and 28 show the modeled potentiometric surface.

B.3.5 Alternative 2C – Reactive bio-barrier for containment

This alternative uses wells in the B and C sands at the southern site boundary, along with upgradient injection of amended groundwater containing donor compound. A reactive zone between the injection and extraction wells would be developed to degrade the contaminants. A mound develops along the line of injection wells, which results in some spread of the plume, which is subsequently captured by the downgradient extraction wells. This alternative has the advantage of avoiding above ground treatment, but will require use of double contained pipe and possibly leak detection systems.

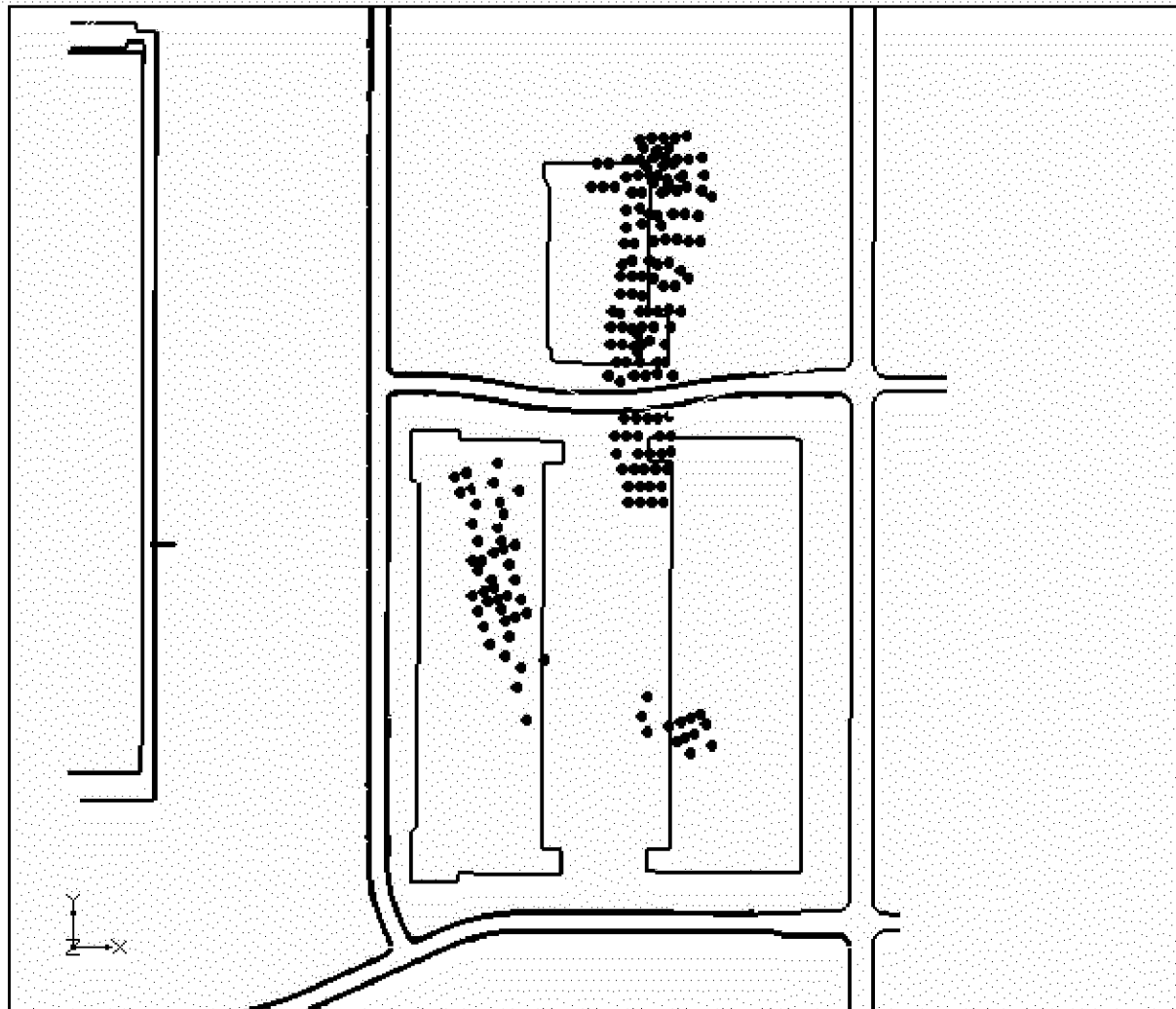
Modeling simulations indicate that this alternative can meet the objective of minimizing

off-site migration of contaminants at high concentrations; however, this alternative would require long-term operations, since no enhanced treatment occurs within the source area. This alternative also is projected to increase the extent of the high concentrations by spreading the contamination laterally. This potential for lateral extension of the extent of contamination limits applicability of this alternative. Figures 29 through 32 show the locations of extraction and treatment wells in the B and C zones, while Figures 33 and 34 show the modeled potentiometric surface for both zones. Figures 35 and 36 show the donor distribution in the B and C sands.

B.3.6 Alternatives 2B/2D/2E – Boundary containment combined with ISEB at new injection wells

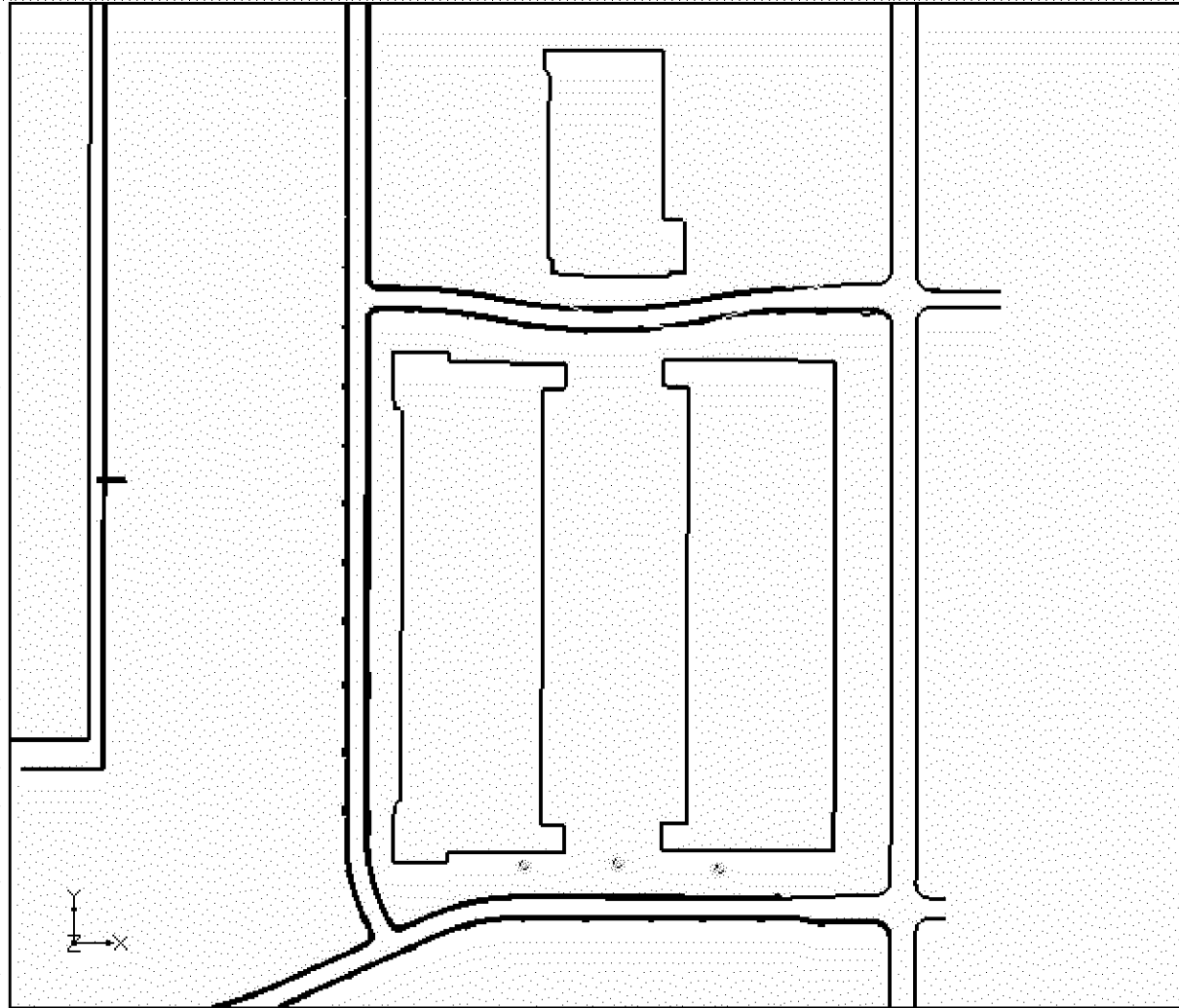
This alternative consists of boundary containment to minimize migration of contaminant concentrations greater than 1,000 µg/L off of the site, combined with continuous injection at new wells. Existing wells are not utilized in this alternative. This alternative provides moderate coverage of the source areas, since areas under the buildings are not accessible, even with use of angle drilling techniques to install the new wells. The containment objective can be met with this alternative. Figures 37 through 40 show the location of treatment and extraction wells for both zones. Figure 41 and 42 show the modeled potentiometric surfaces, while Figures 43 and 44 show the donor distribution.

Attachments (Modeling Simulations) - Figures 1 through 44



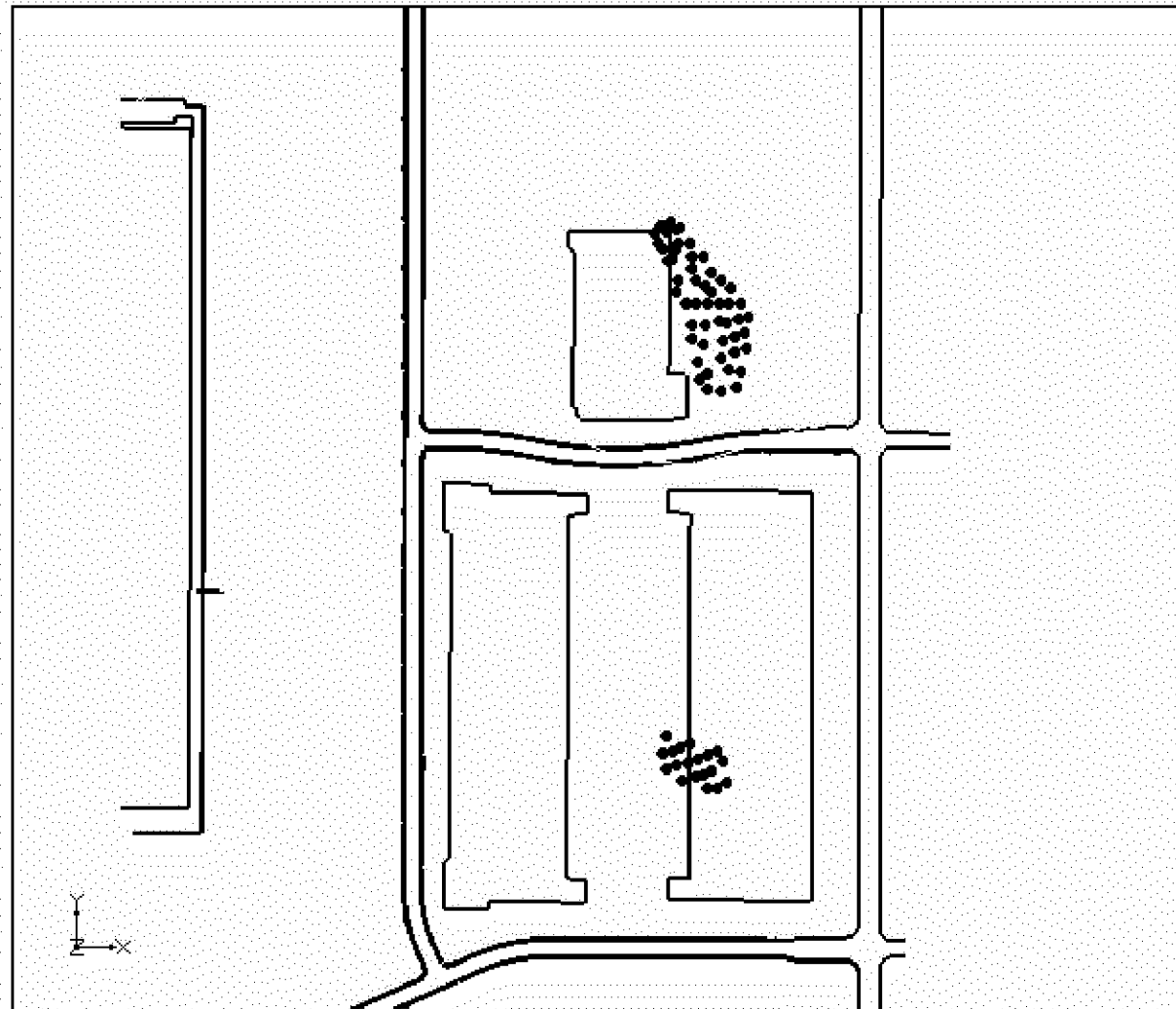
CDM

Figure 1 – Scenario 1A (B-Sand) Injection Wells
Former C-6 Facility



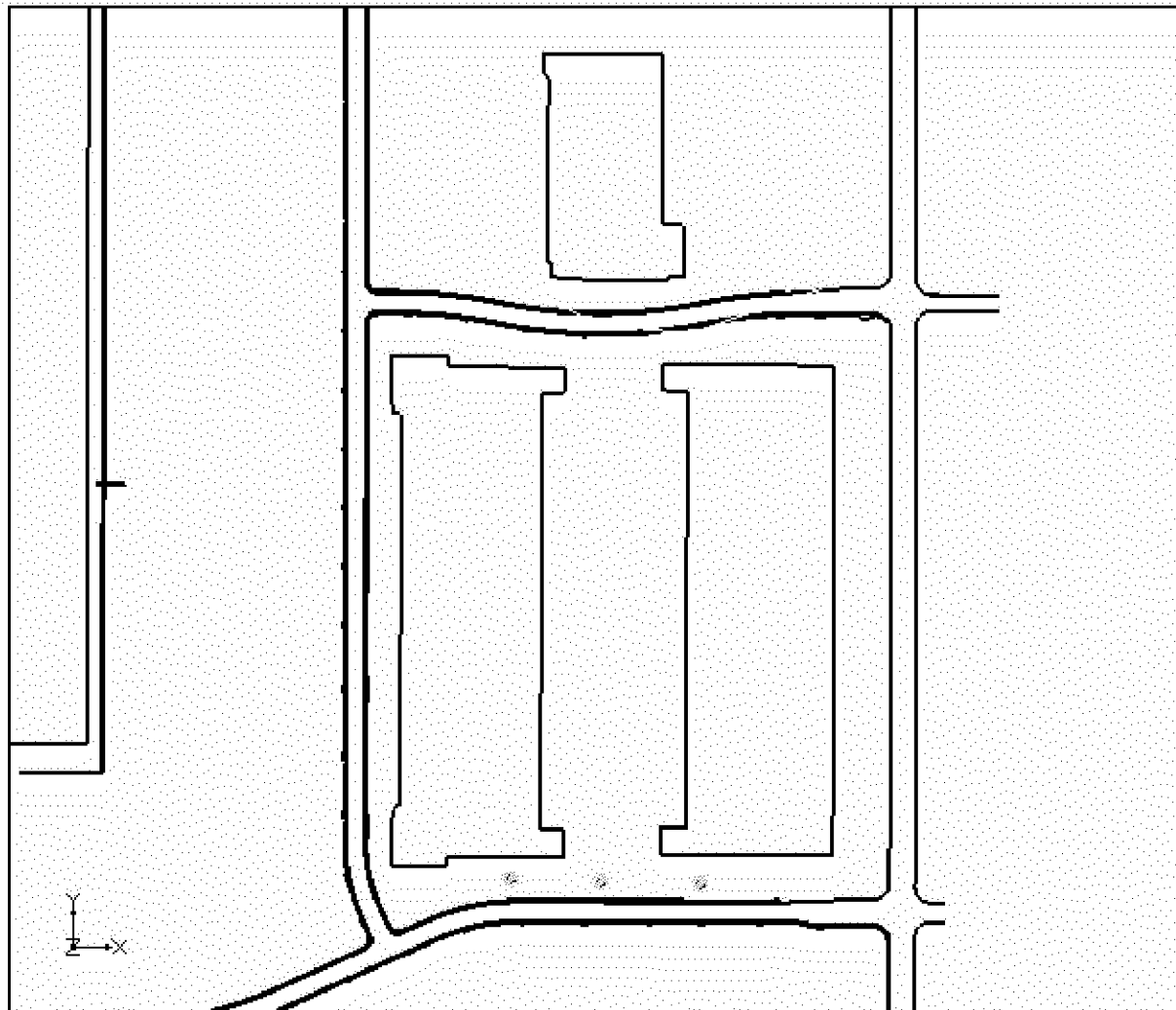
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Figure 2 – Scenario 1A (B-Sand) Pumping Wells
Former C-6 Facility



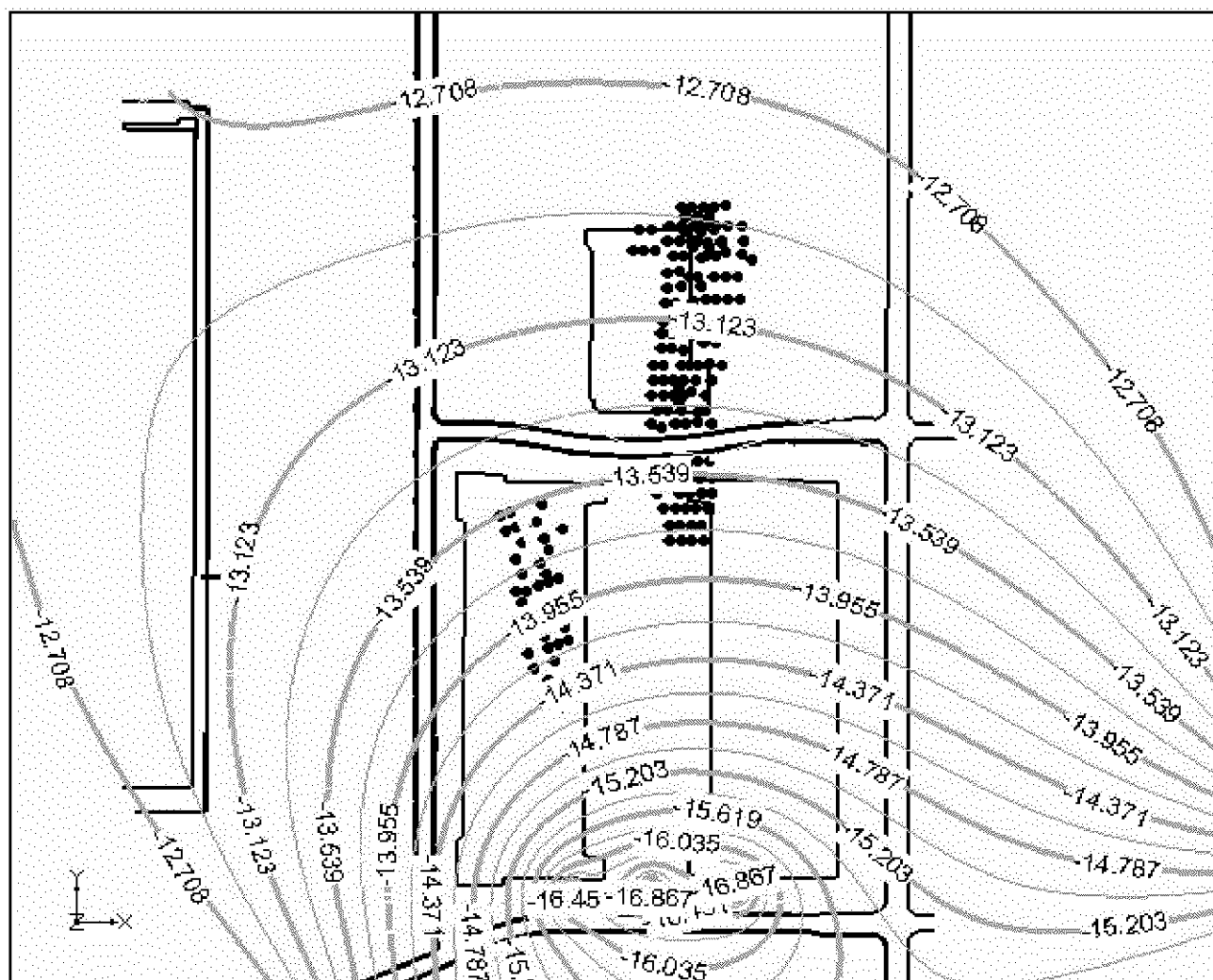
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Figure 3 – Scenario 1A (C-Sand) Injection Wells
Former C-6 Facility



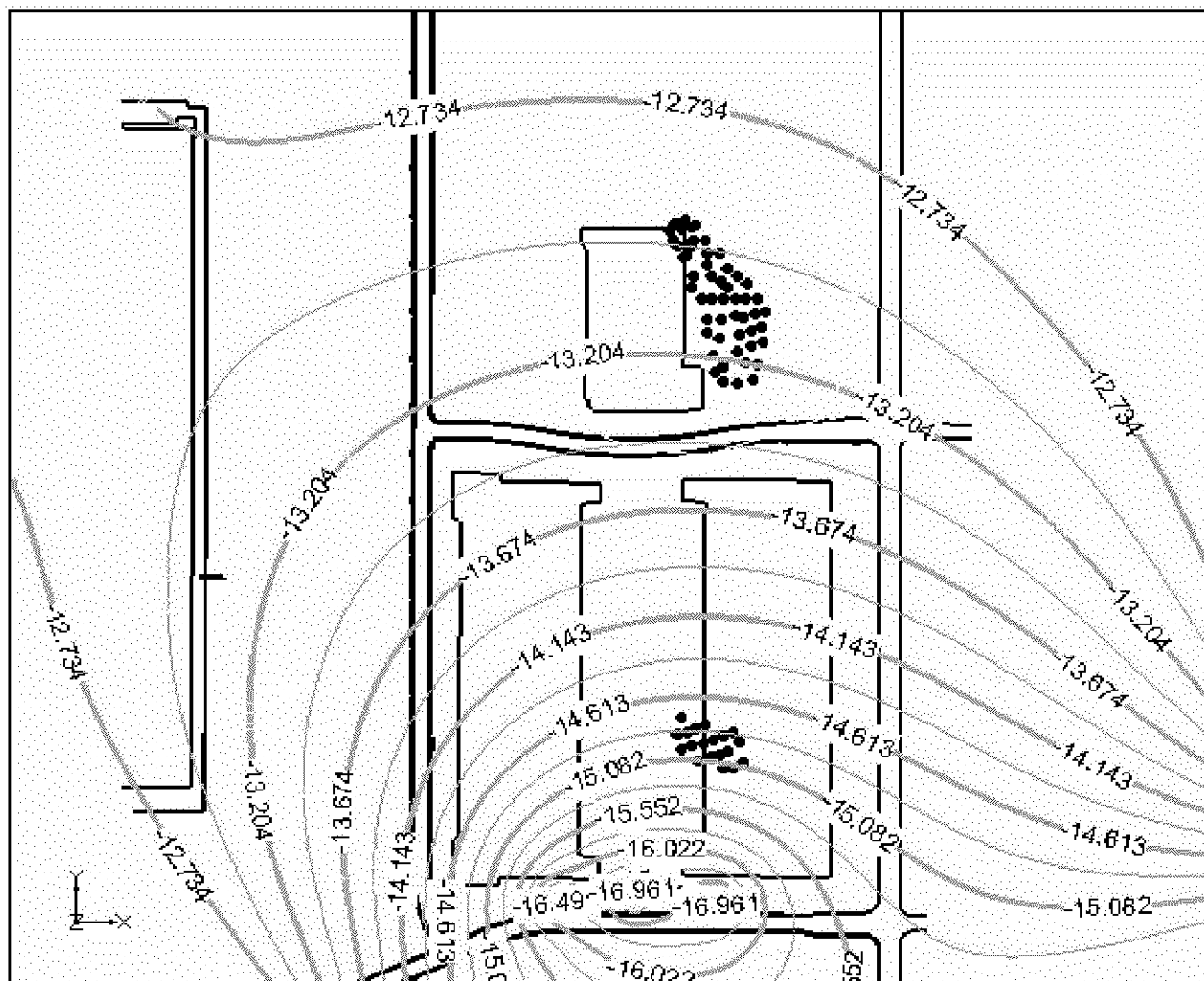
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Figure 4 – Scenario 1A (C-Sand) Pumping Wells
Former C-6 Facility



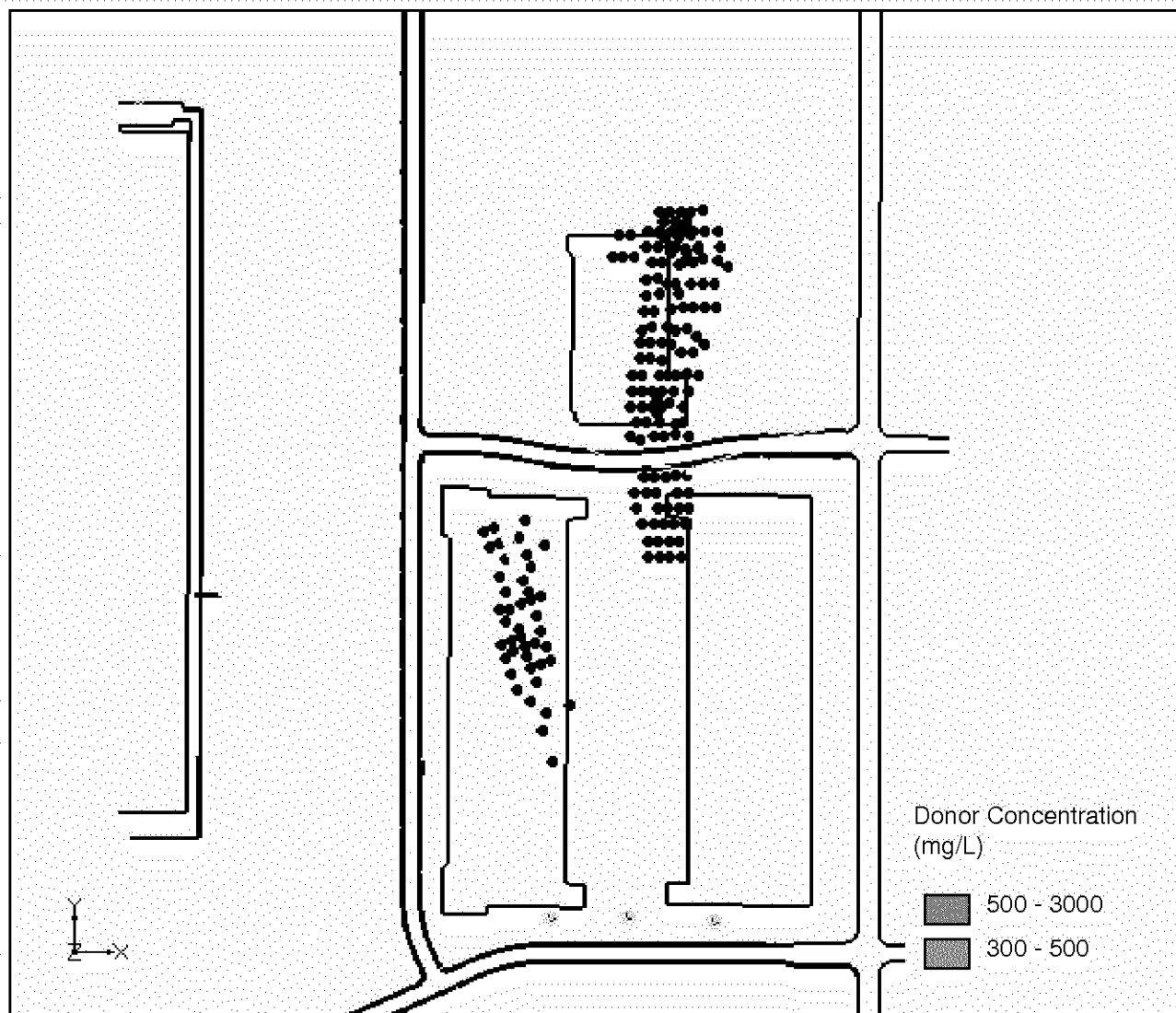
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Figure 5 – Scenario 1A (B-Sand) Potentiometric Surface
Former C-6 Facility



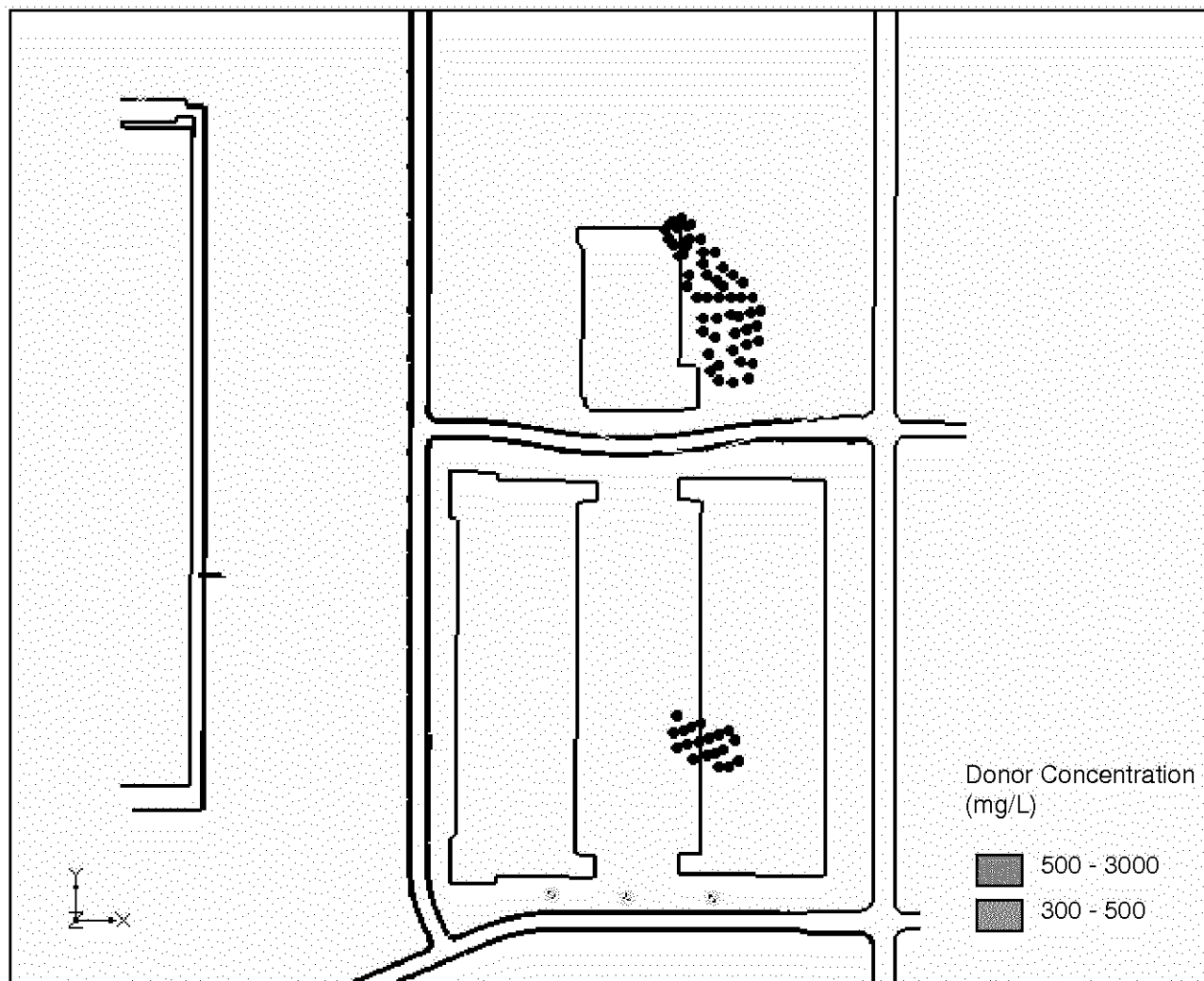
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Figure 6 – Scenario 1A (C-Sand) Potentiometric Surface
Former C-6 Facility



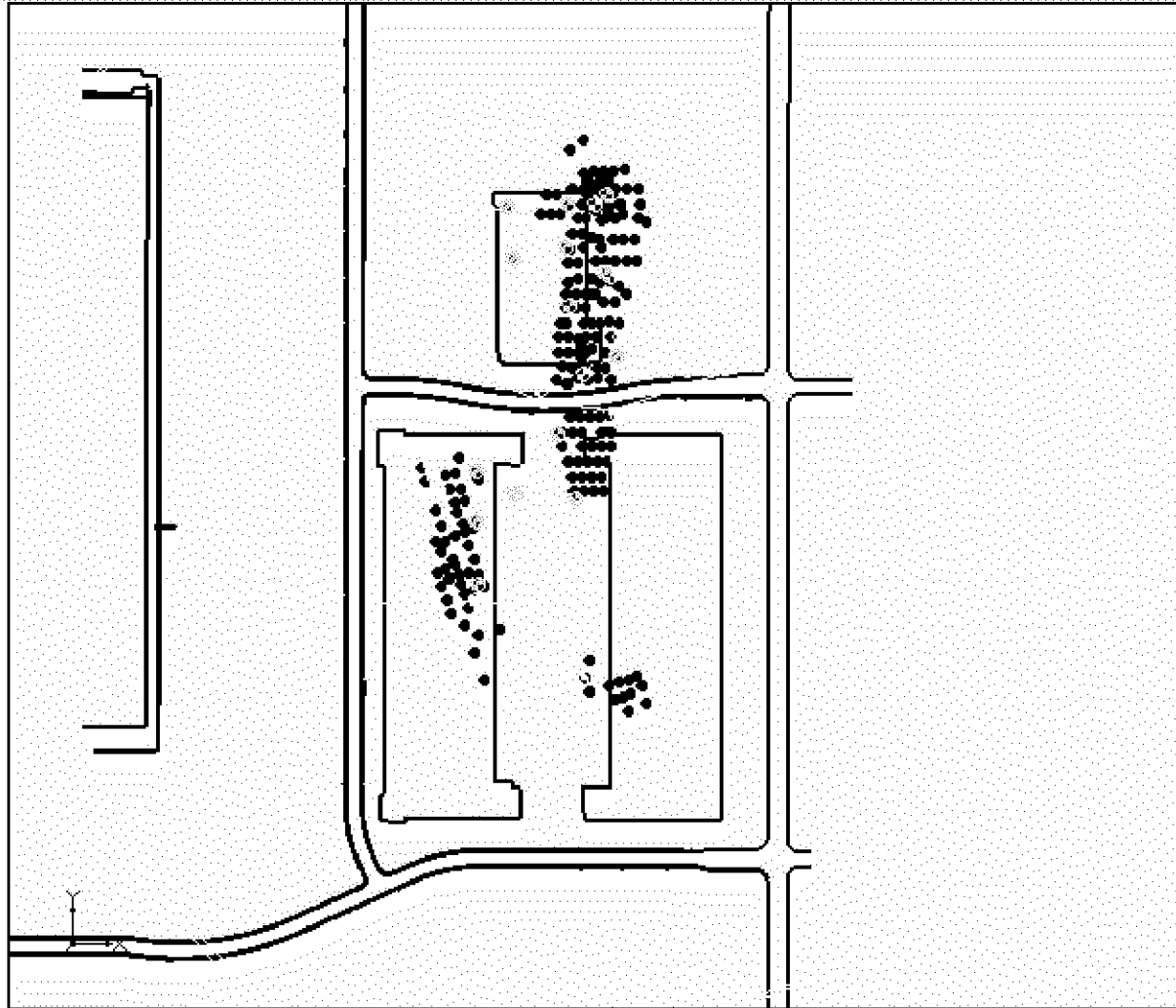
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Figure 7 – Scenario 1A (B-Sand) Estimated Donor Compound Extent
Former C-6 Facility



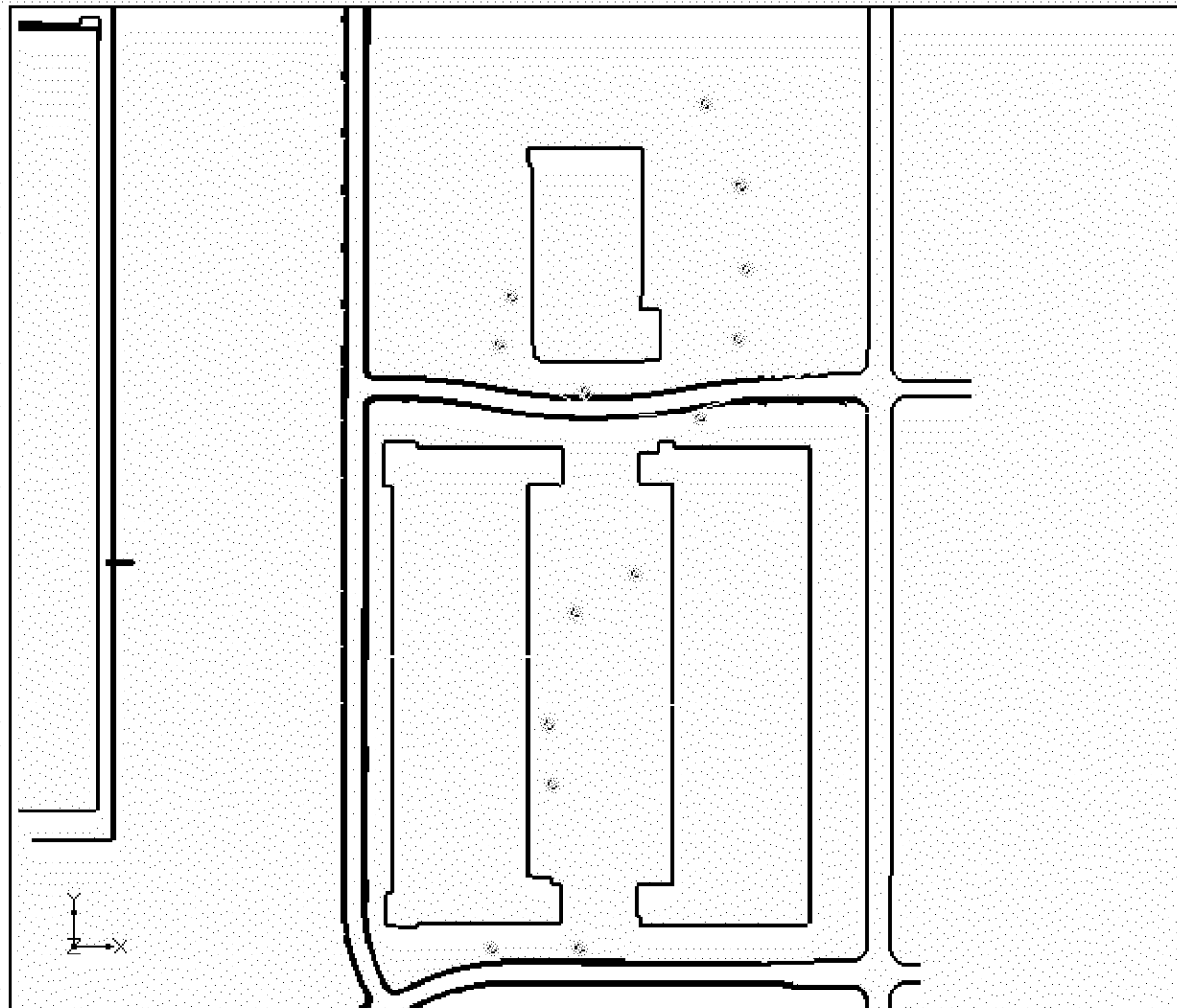
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Figure 8 – Scenario 1A (C-Sand) Estimated Donor Compound Extent
Former C-6 Facility



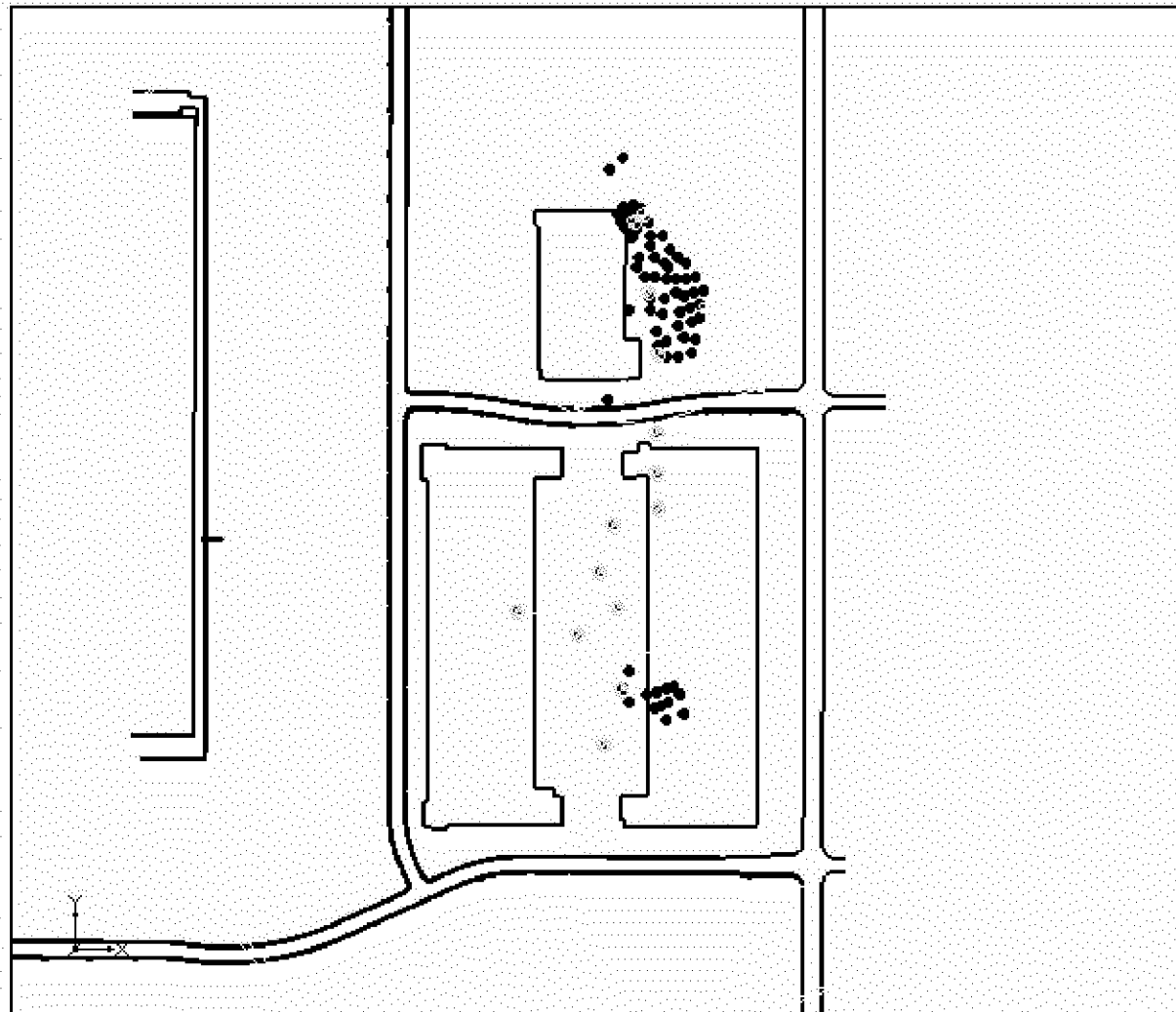
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Figure 9 – Scenario 1B/1D/1F (B-Sand) Injection Wells
Former C-6 Facility



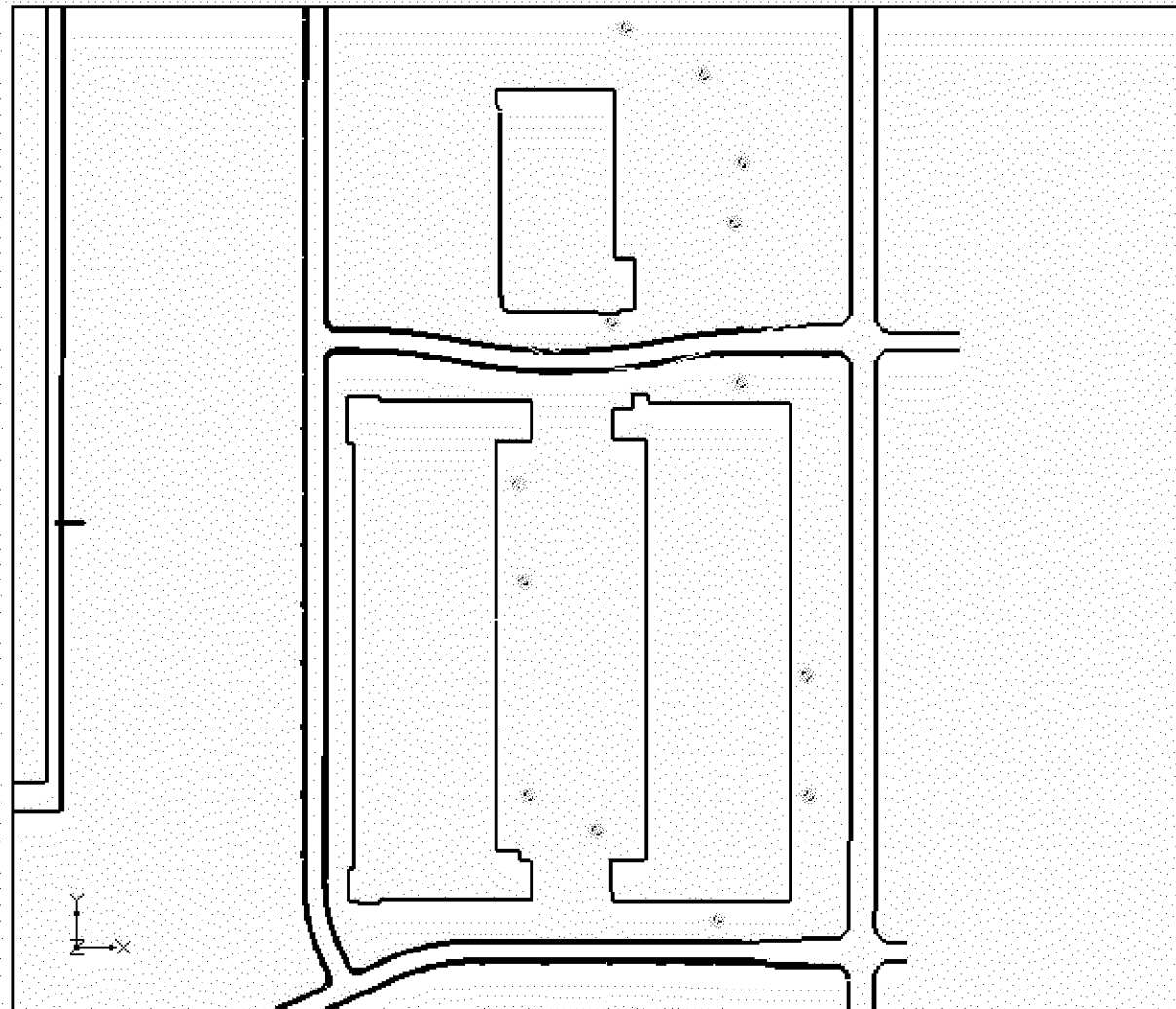
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Figure 10 – Scenario 1B/1D/1F (B-Sand) Pumping Wells
Former C-6 Facility



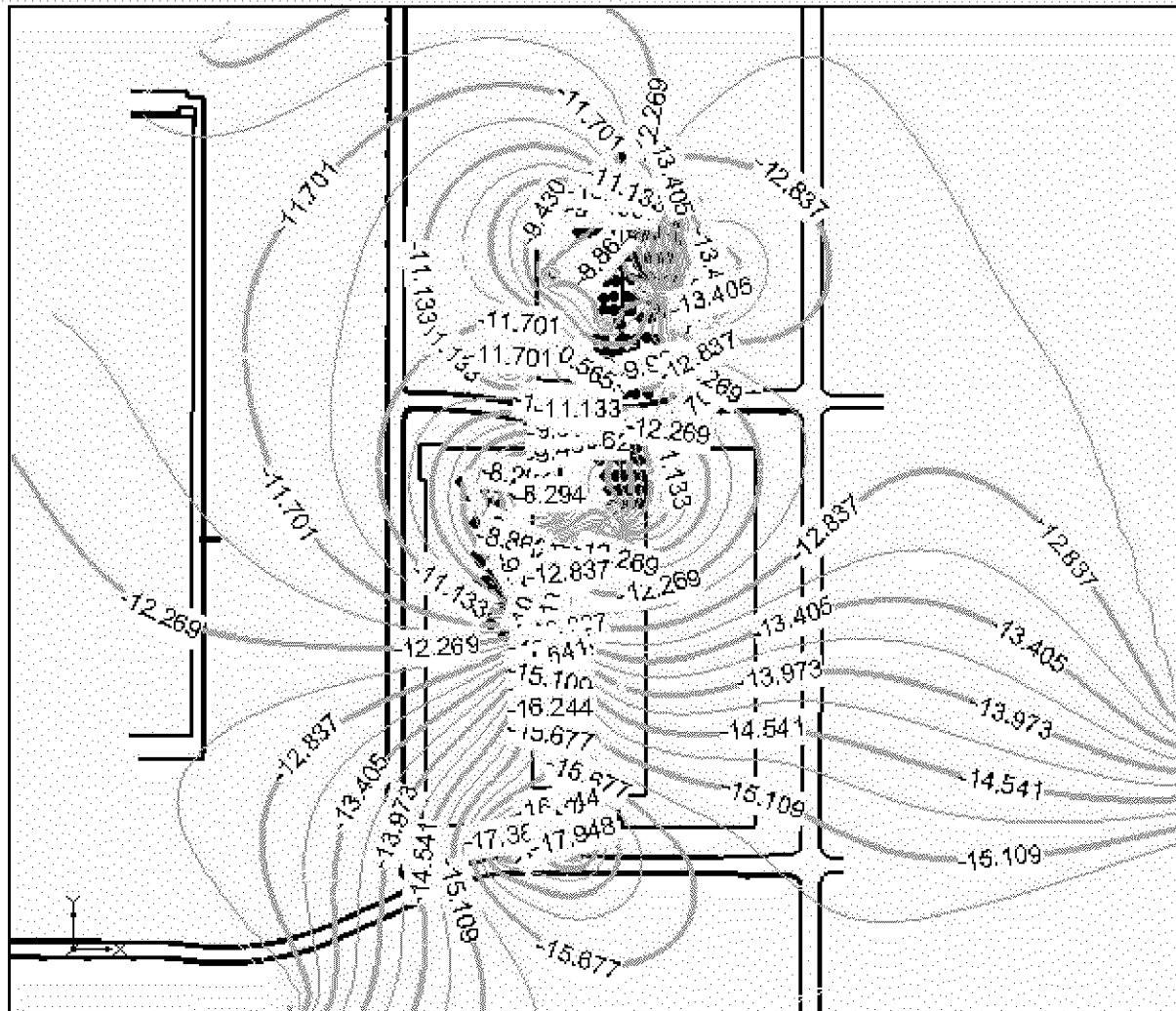
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Figure 11 – Scenario 1B/1D/1F (C-Sand) Injection Wells
Former C-6 Facility



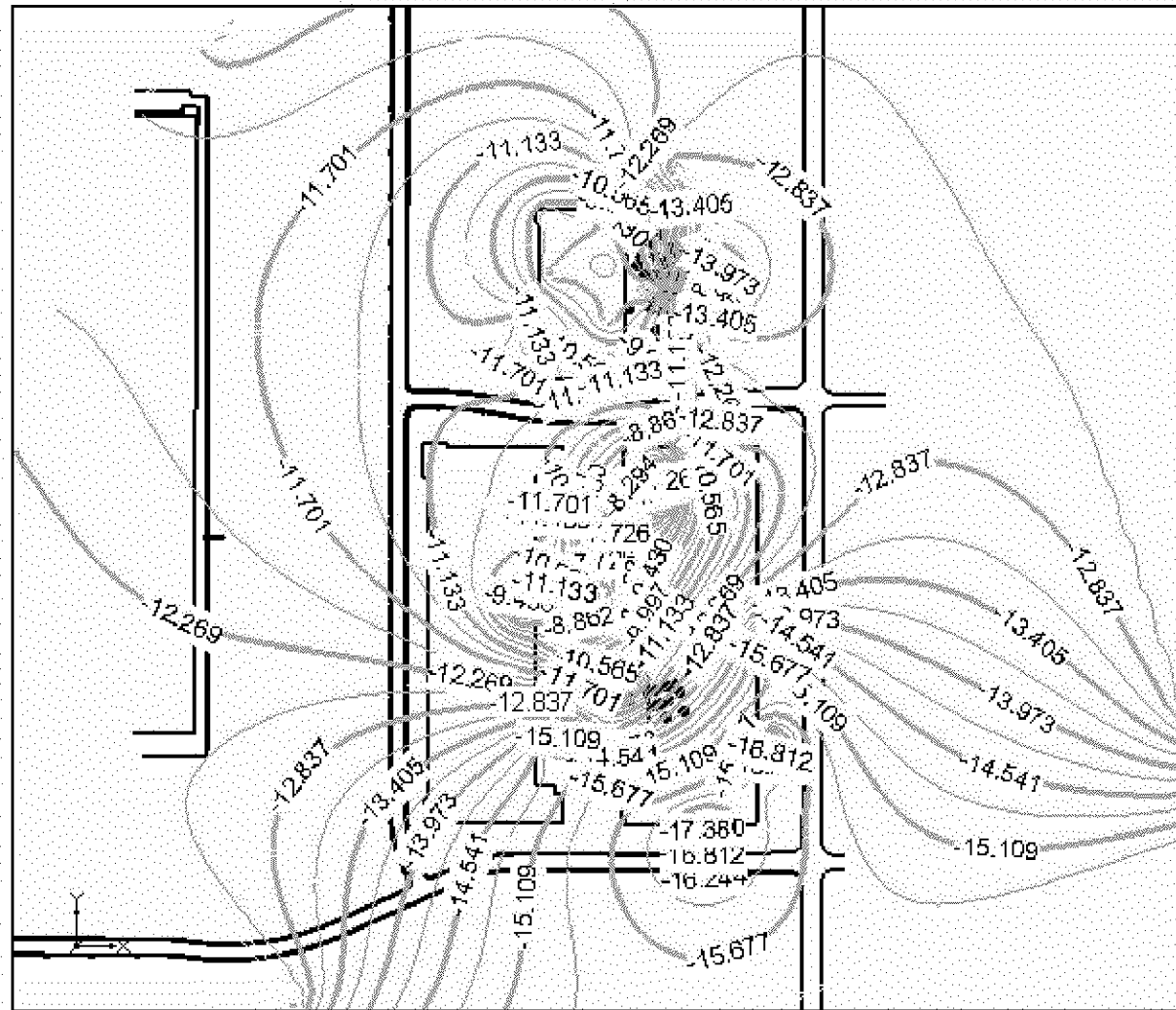
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Figure 12 – Scenario 1B/1D/1F (C-Sand) Pumping Wells
Former C-6 Facility



CDM

Figure 13 – Scenario 1B/1D/1F (B-Sand) Potentiometric Surface
Former C-6 Facility



CDM

Figure 14 – Scenario 1B/1D/1F (C-Sand) Potentiometric Surface
Former C-6 Facility



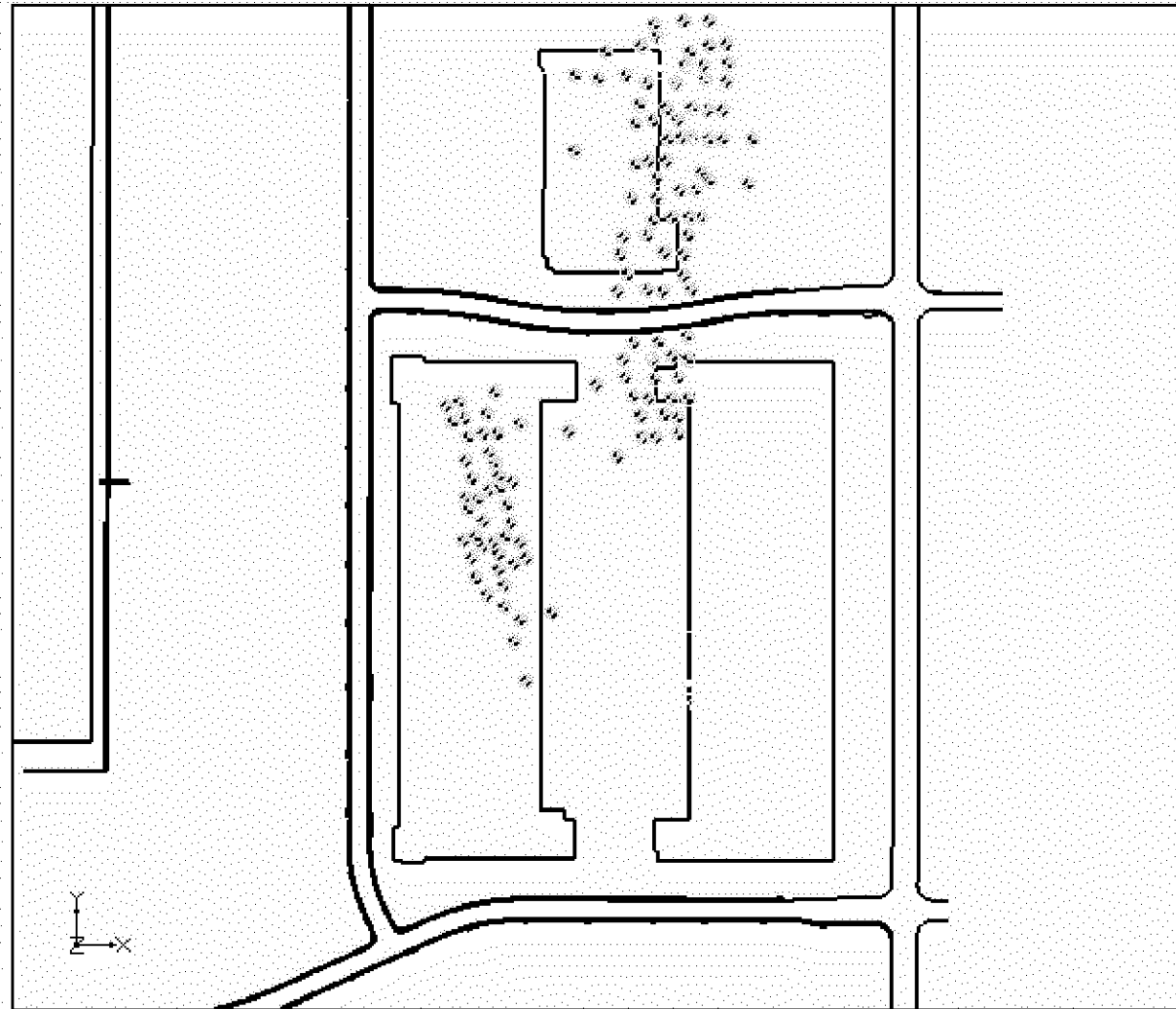
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Figure 15 – Scenario 1B/1D/1F (B-Sand) Estimated Donor Compound Extent
Former C-6 Facility



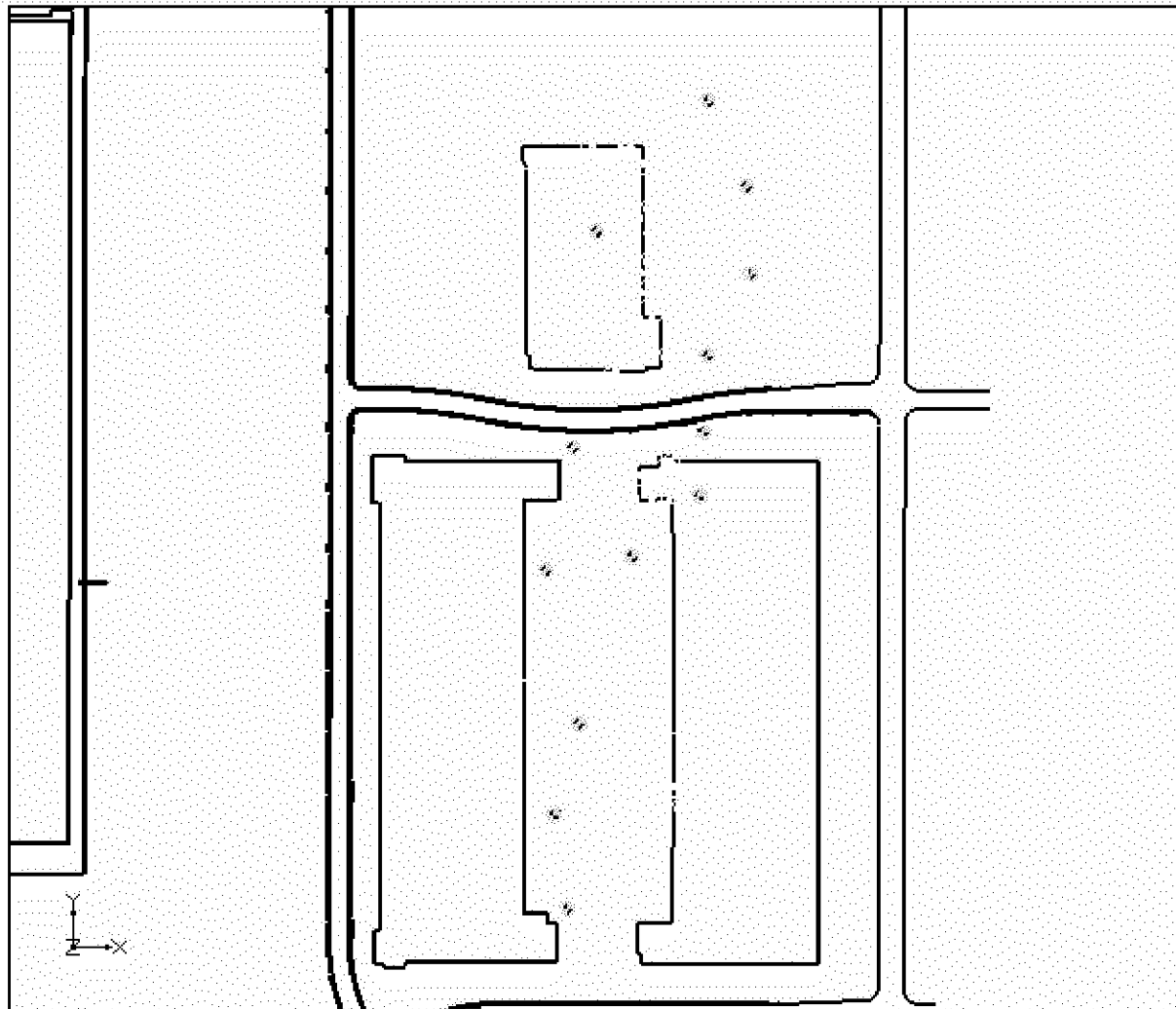
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Figure 16 – Scenario 1B/1D/1F (C-Sand) Estimated Donor Compound Extent
Former C-6 Facility



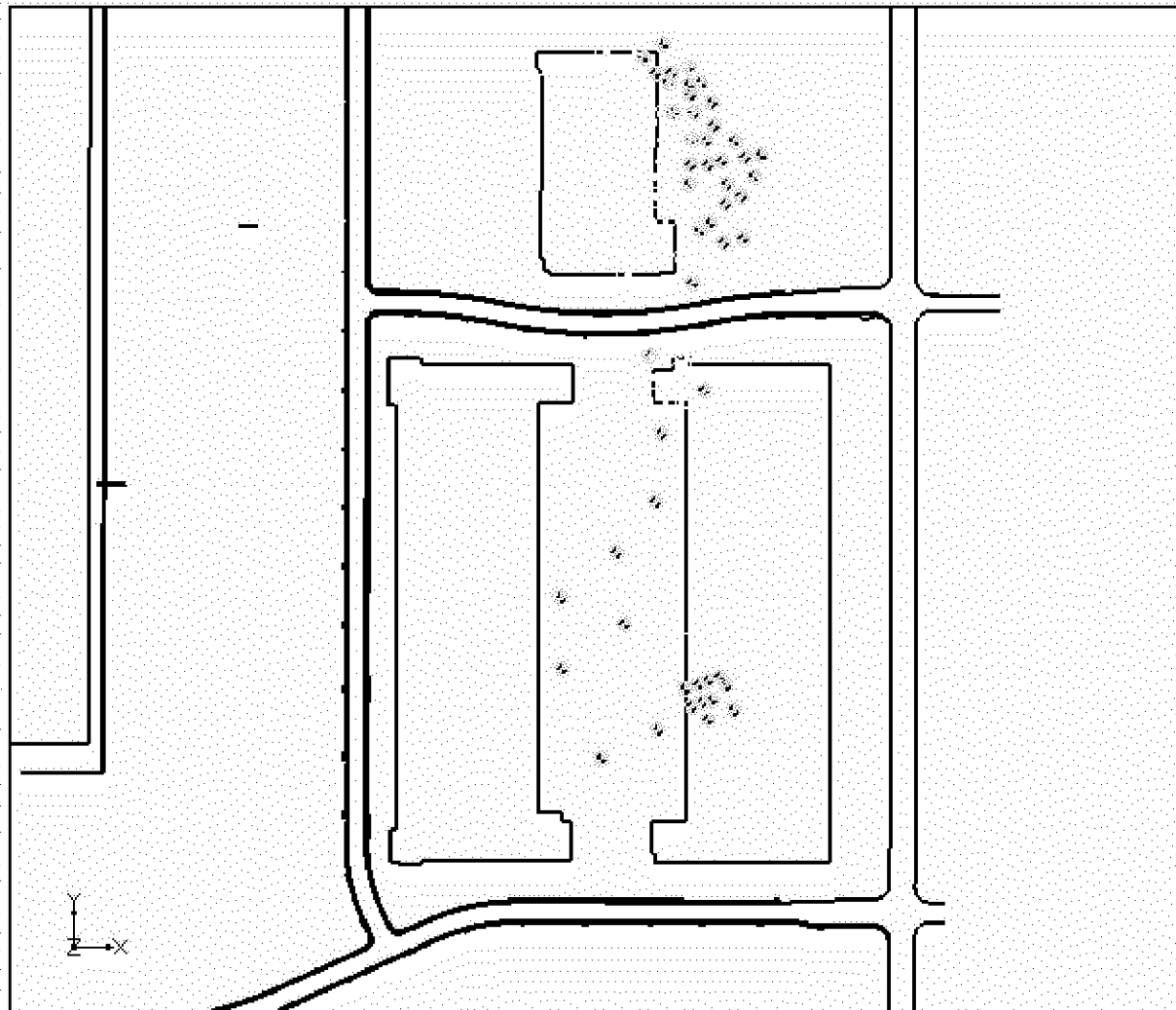
CDM

Figure 17 – Scenario 1E/1G (B-Sand) Injection Wells
Former C-6 Facility



CDM

Figure 18 – Scenario 1E/1G (B-Sand) Pumping Wells
Former C-6 Facility



CDM

Figure 19 – Scenario 1E/1G (C-Sand) Injection Wells
Former C-6 Facility

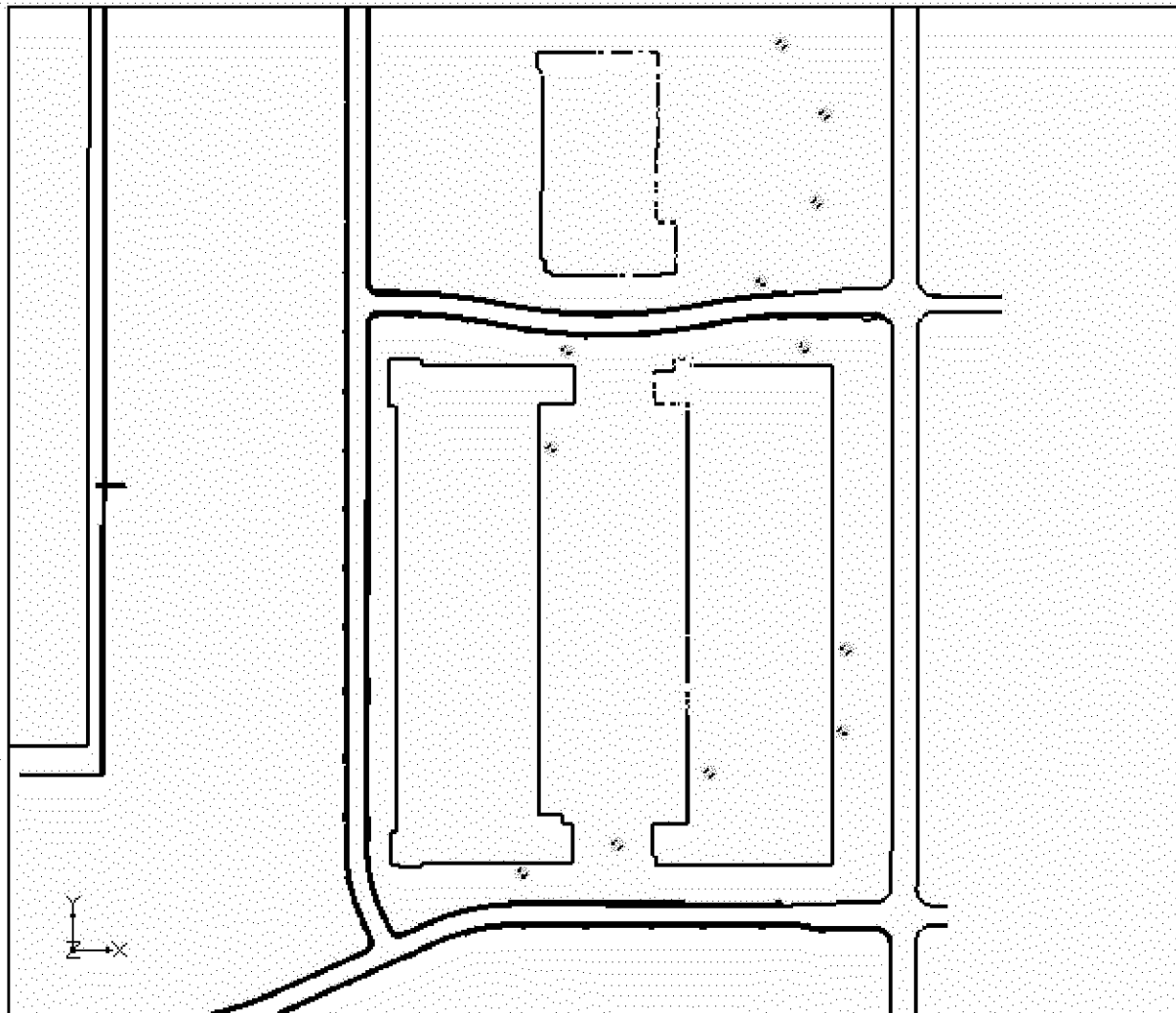


Figure 20 – Scenario 1E/1G (C-Sand) Pumping Wells
Former C-6 Facility



CDM

Figure 21 – Scenario 1E/1G (B-Sand) Potentiometric Surface
Former C-6 Facility

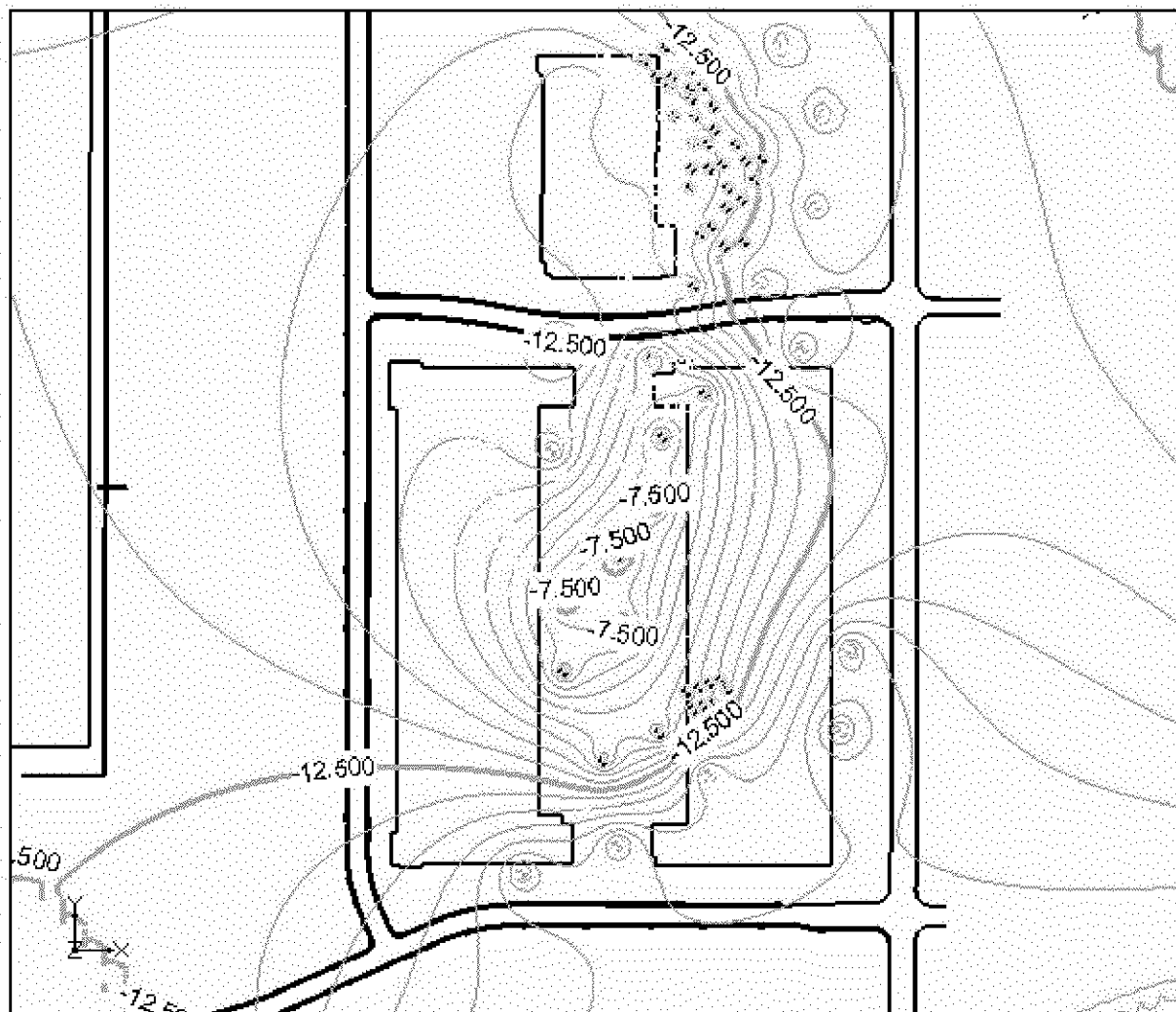


Figure 22 – Scenario 1E/1G (C-Sand) Potentiometric Surface
Former C-6 Facility

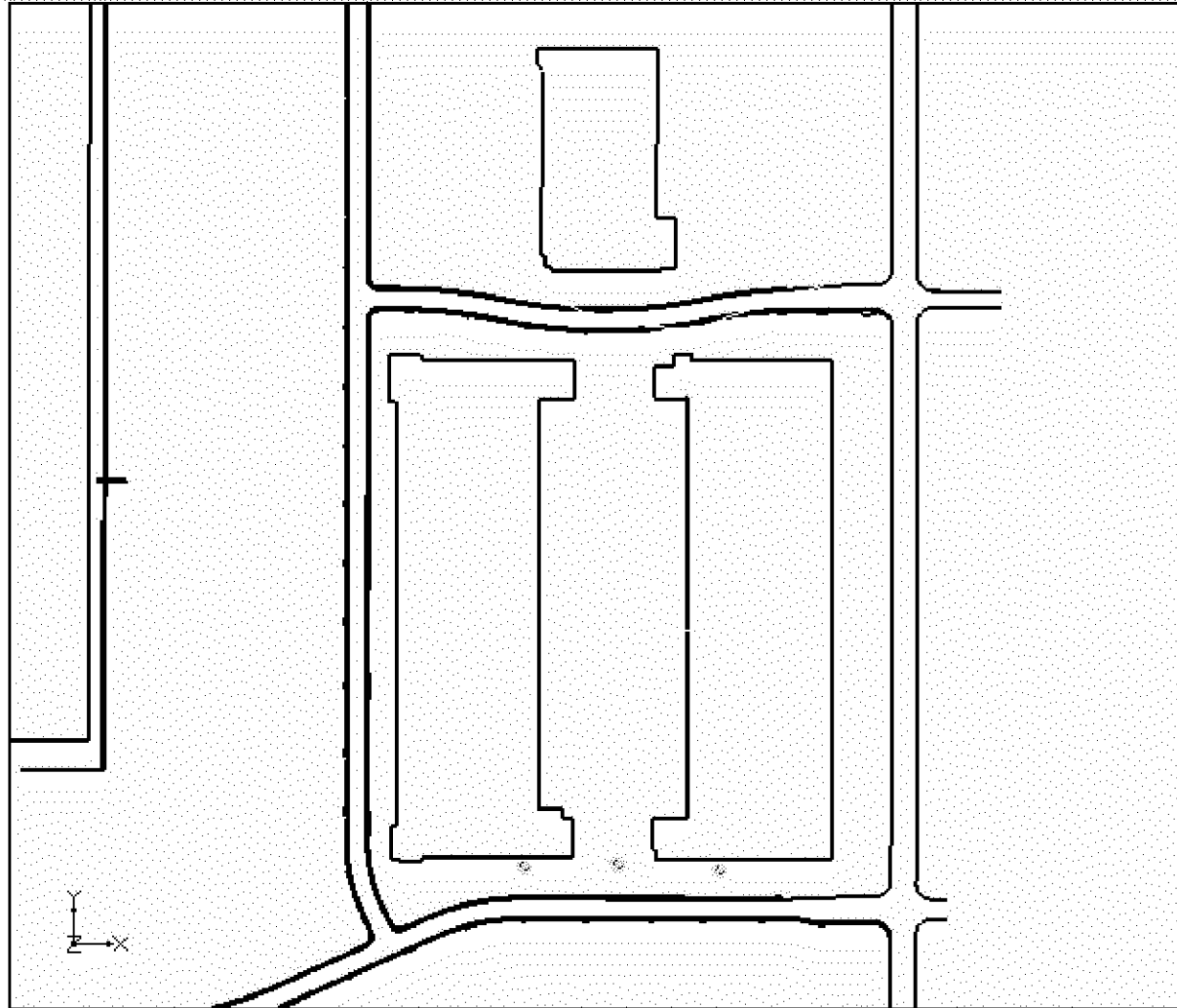


Figure 23 – Scenario 1E/1G (B-Sand) Estimated Donor Compound Extent
Former C-6 Facility



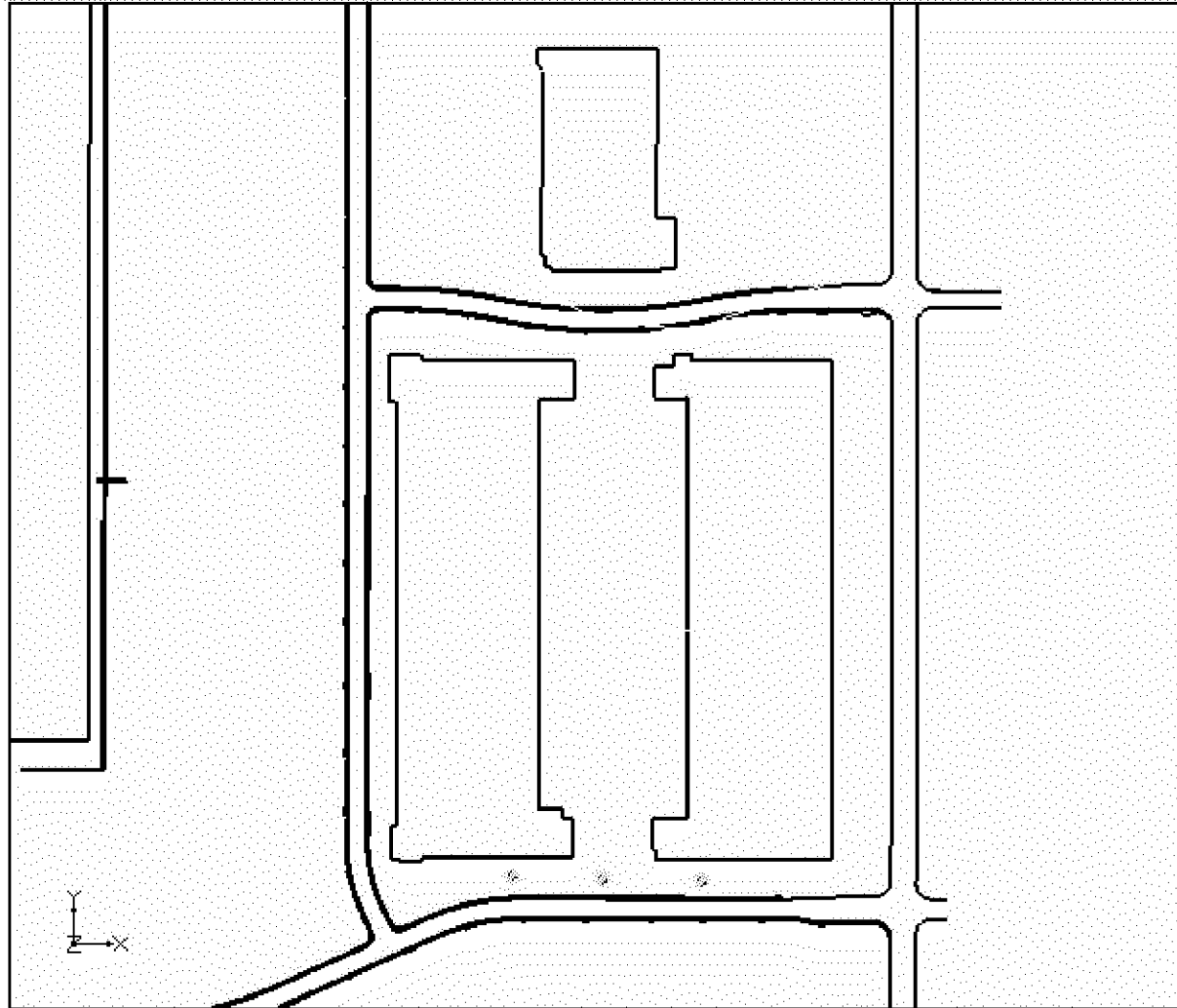
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Figure 24 – Scenario 1E/1G (C-Sand) Estimated Donor Compound Extent
Former C-6 Facility



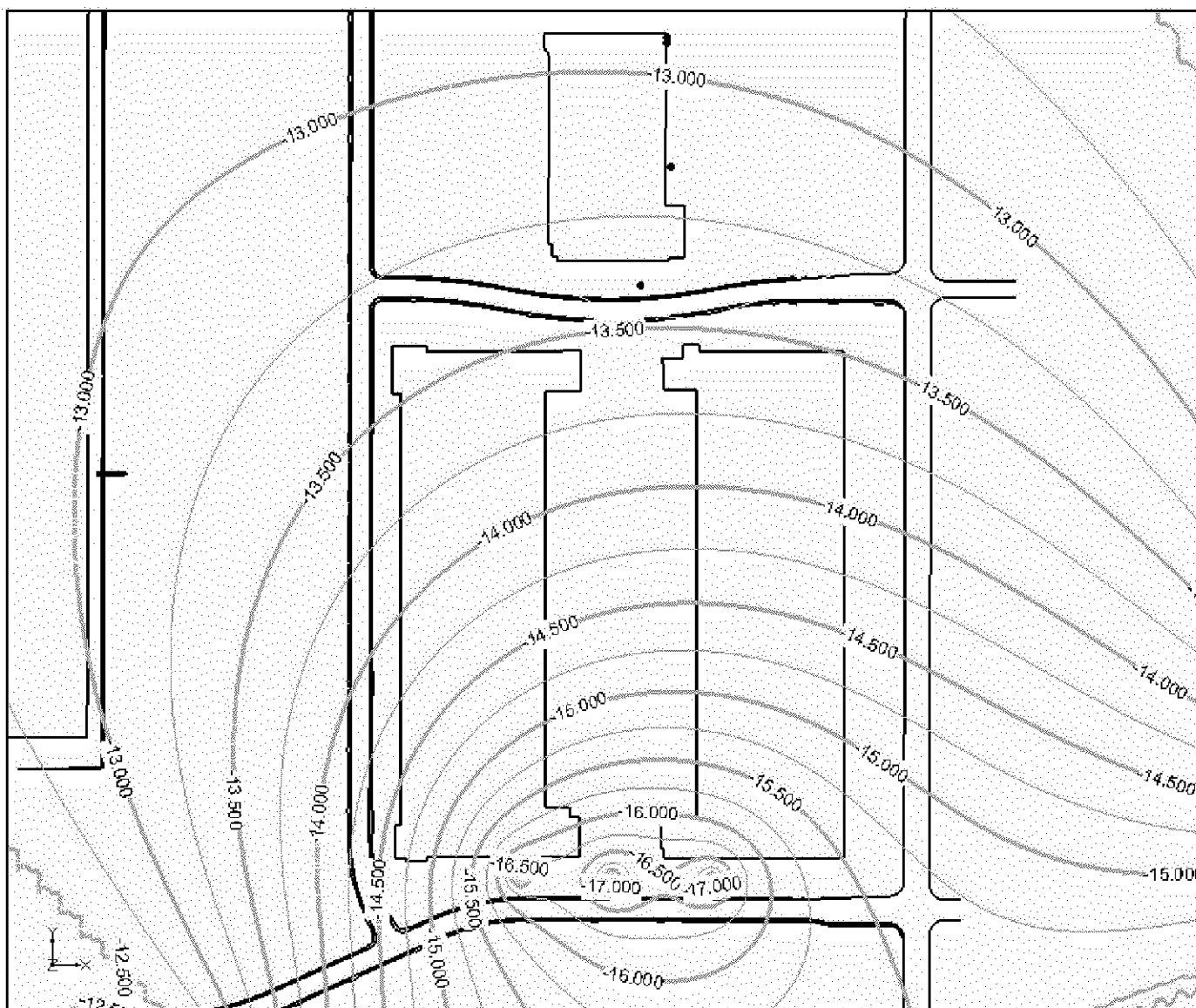
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Figure 25 – Scenario 2A (B-Sand) Pumping Wells
Former C-6 Facility



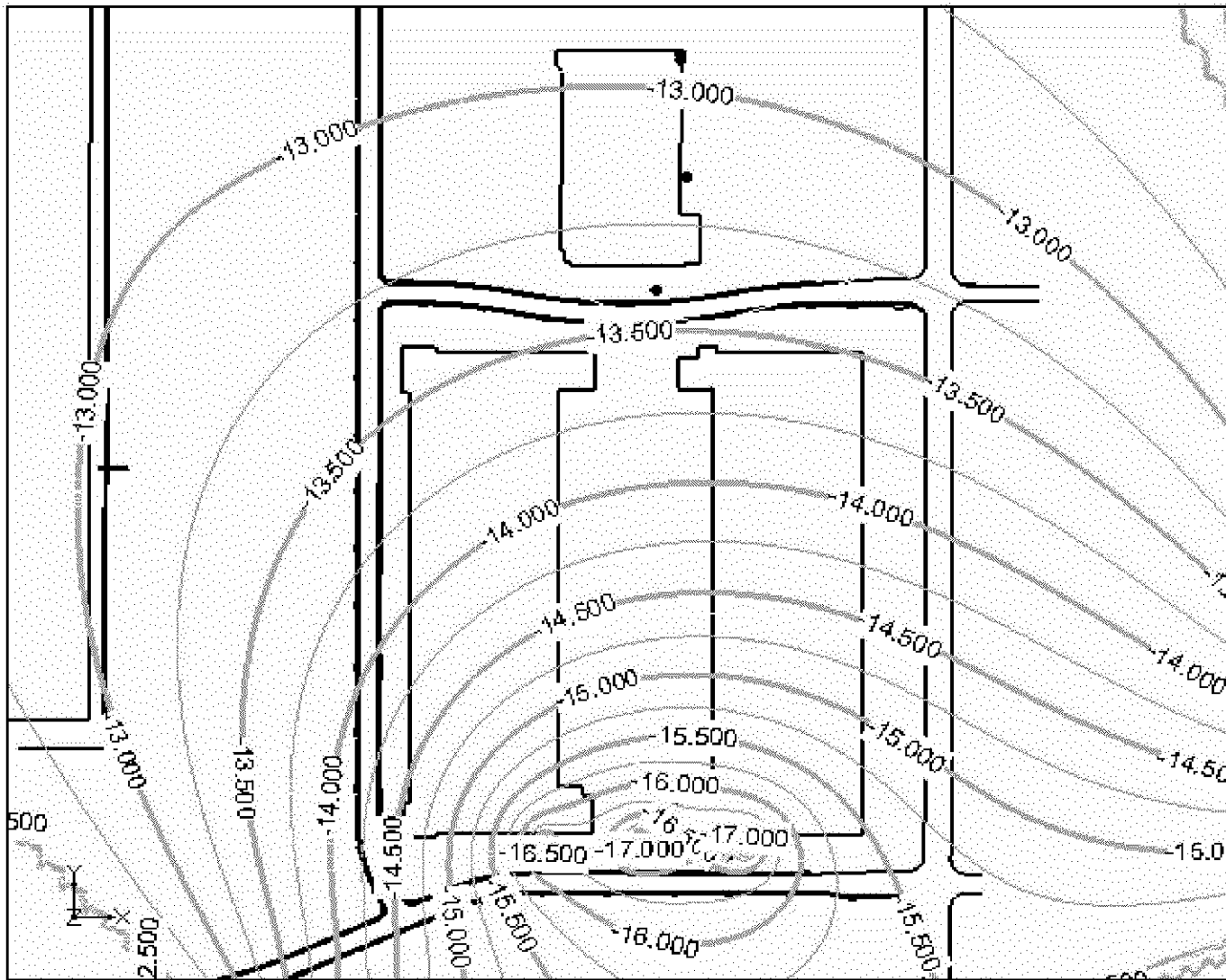
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Figure 26 – Scenario 2A (C-Sand) Pumping Wells
Former C-6 Facility



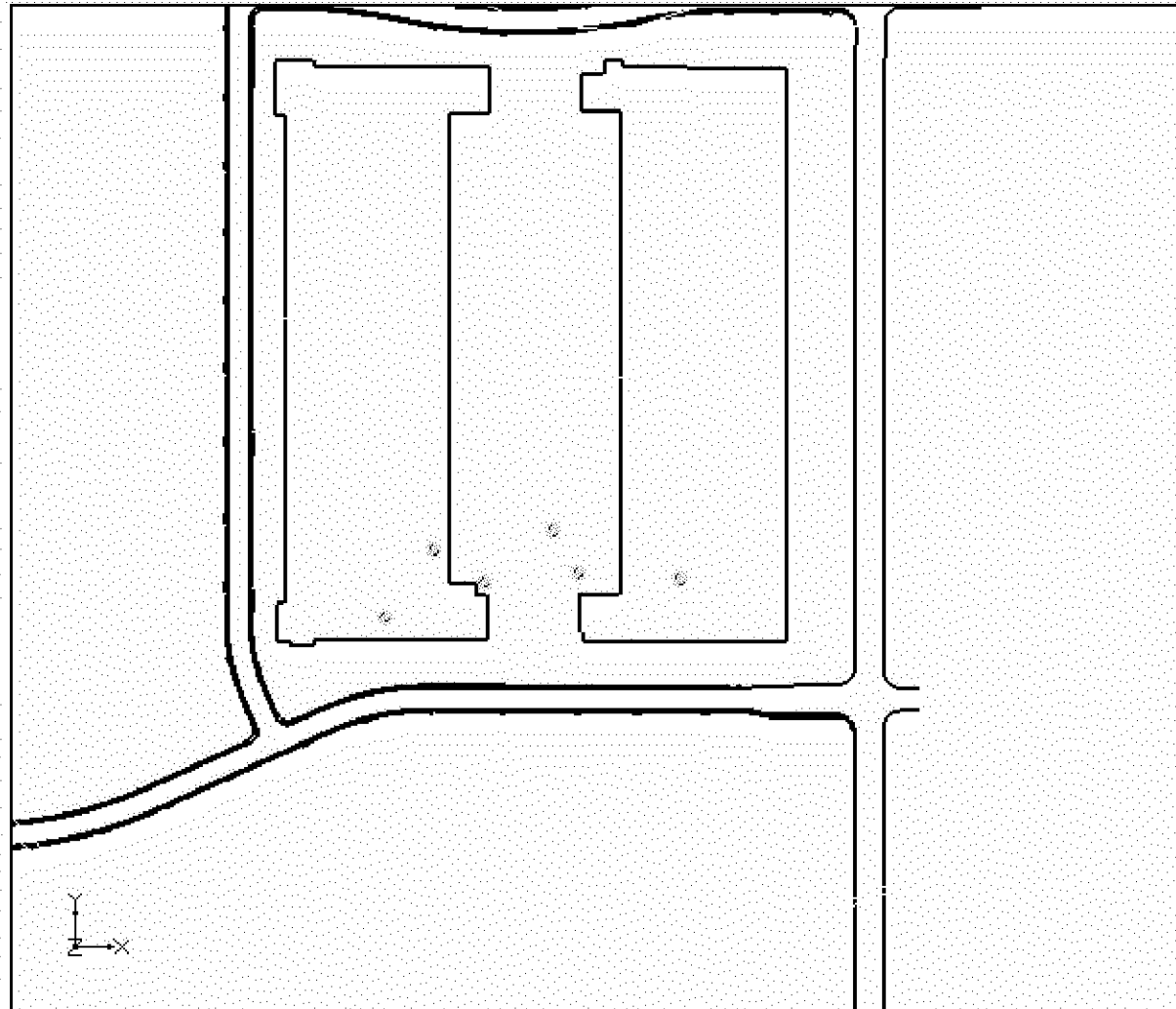
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Figure 27 – Scenario 2A (B-Sand) Potentiometric Surface
Former C-6 Facility



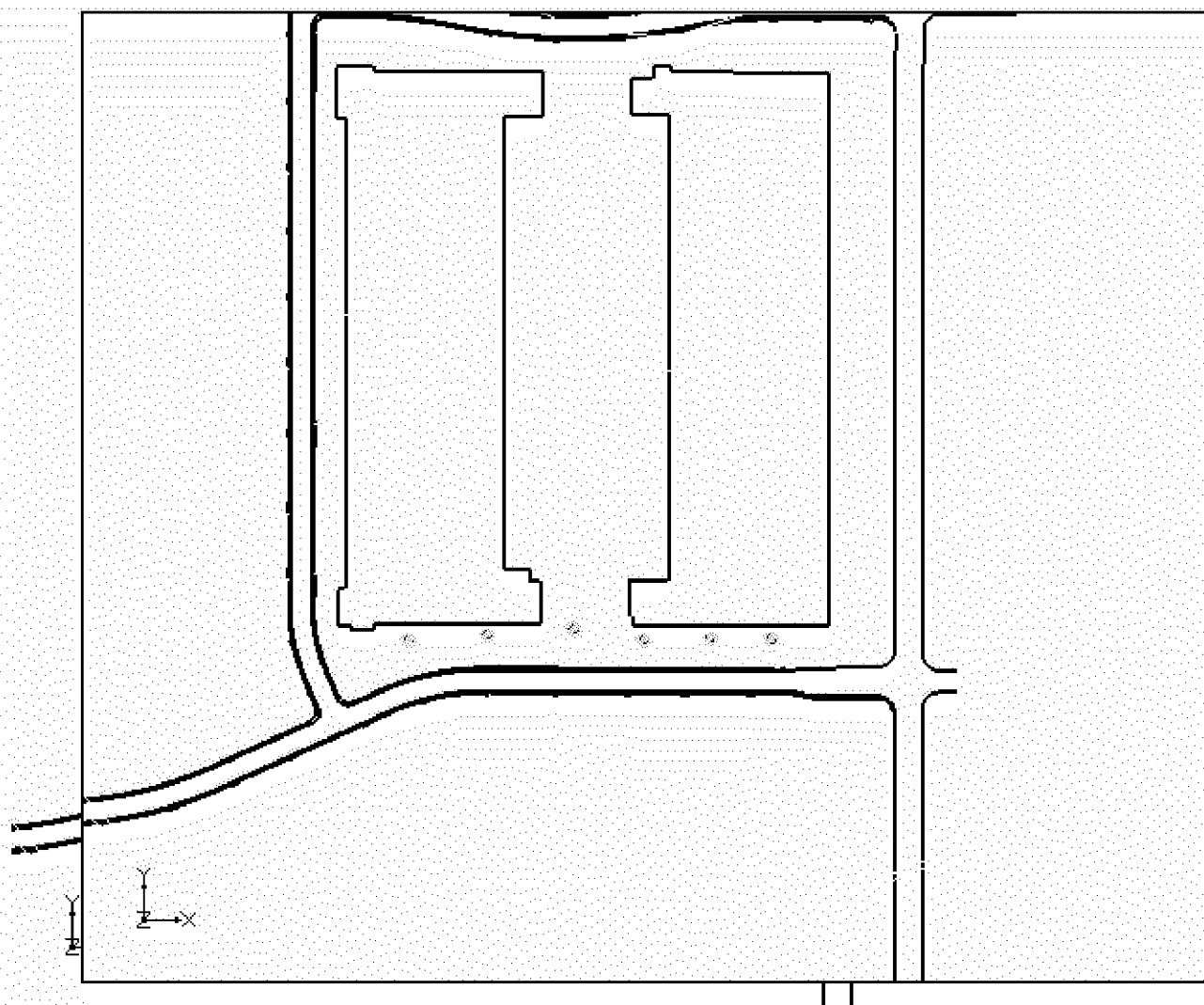
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Figure 28 – Scenario 2A (C-Sand) Potentiometric Surface
Former C-6 Facility



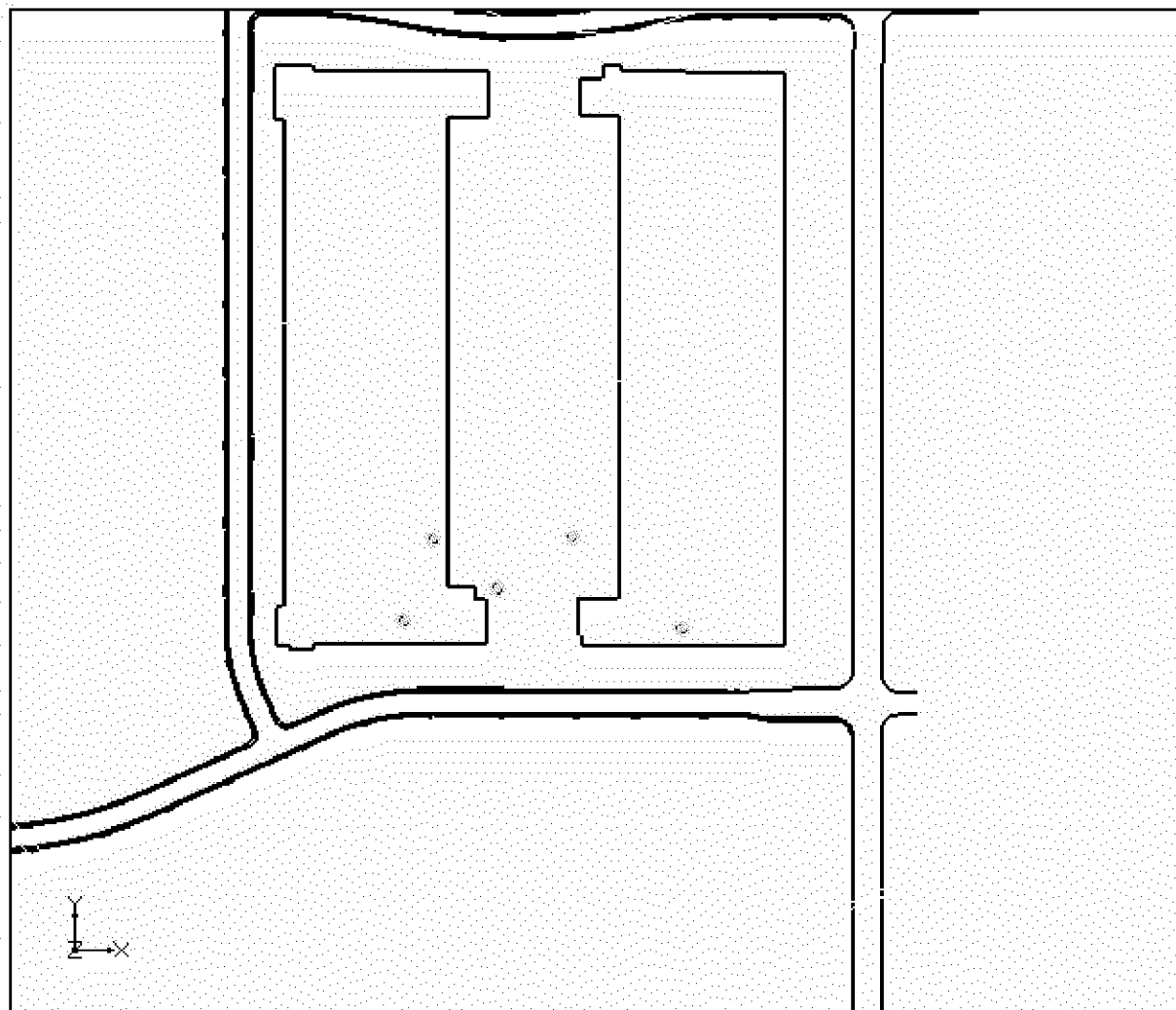
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Figure 29 – Scenario 2C (B-Sand) Injection Wells
Former C-6 Facility



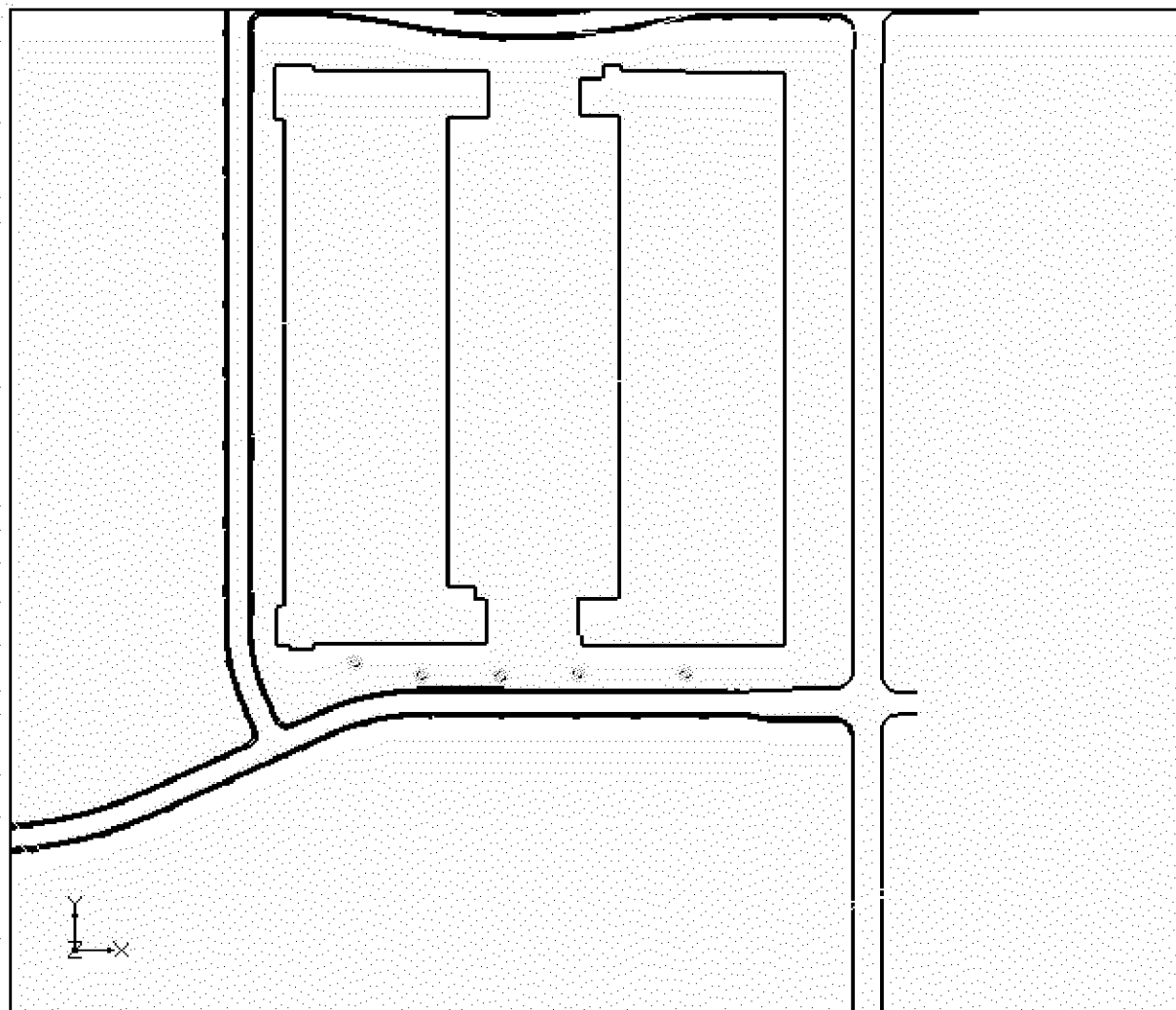
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Figure 30 – Scenario 2C (B-Sand) Pumping Wells
Former C-6 Facility



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Figure 31 – Scenario 2C (C-Sand) Injection Wells
Former C-6 Facility



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Figure 32 – Scenario 2C (C-Sand) Pumping Wells
Former C-6 Facility

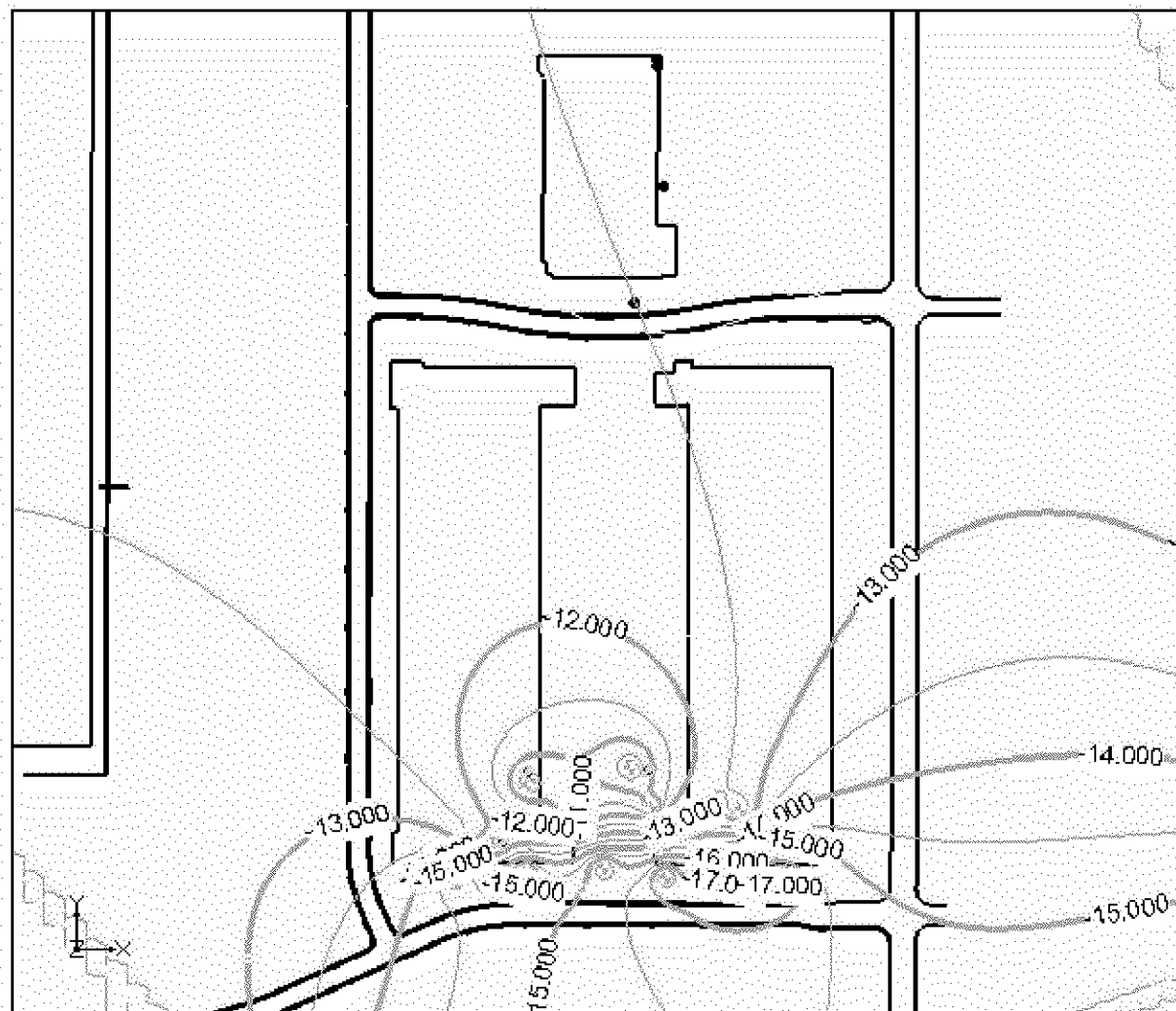


Figure 33 – Scenario 2C (B-Sand) Potentiometric Surface
Former C-6 Facility

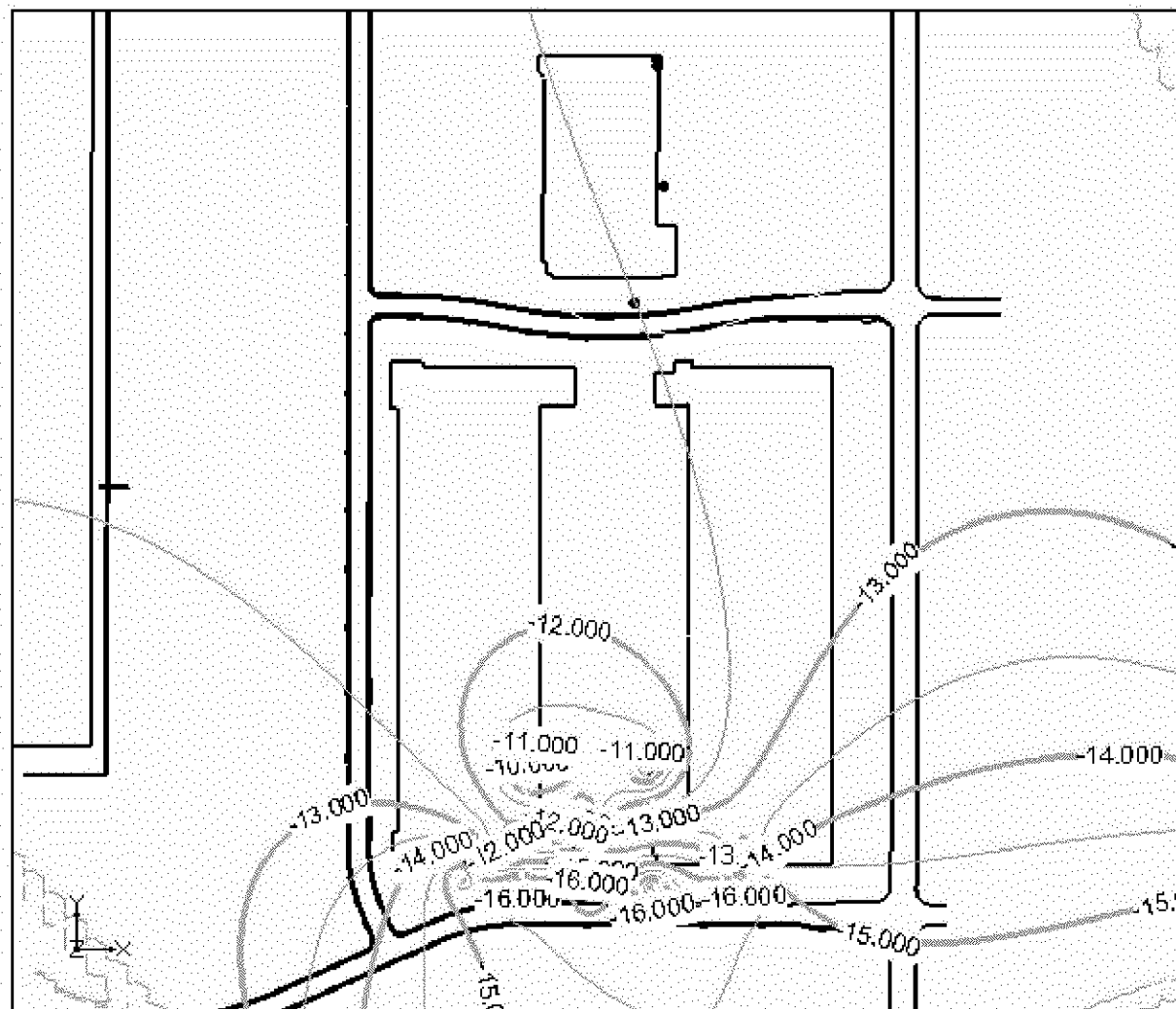


Figure 34 – Scenario 2C (C-Sand) Potentiometric Surface
Former C-6 Facility



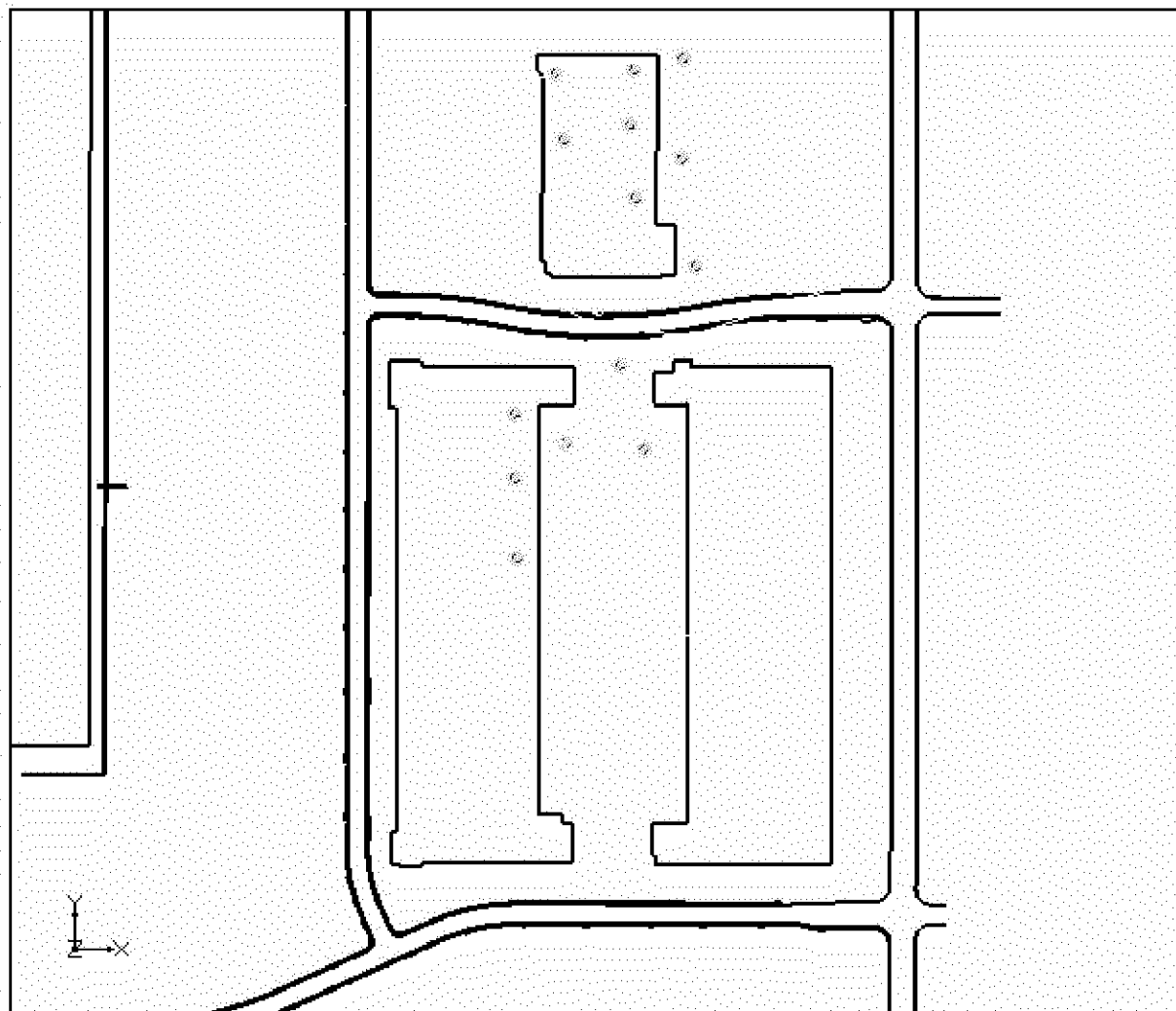
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Figure 35 – Scenario 2C (B-Sand) Estimated Donor Compound Extent
Former C-6 Facility



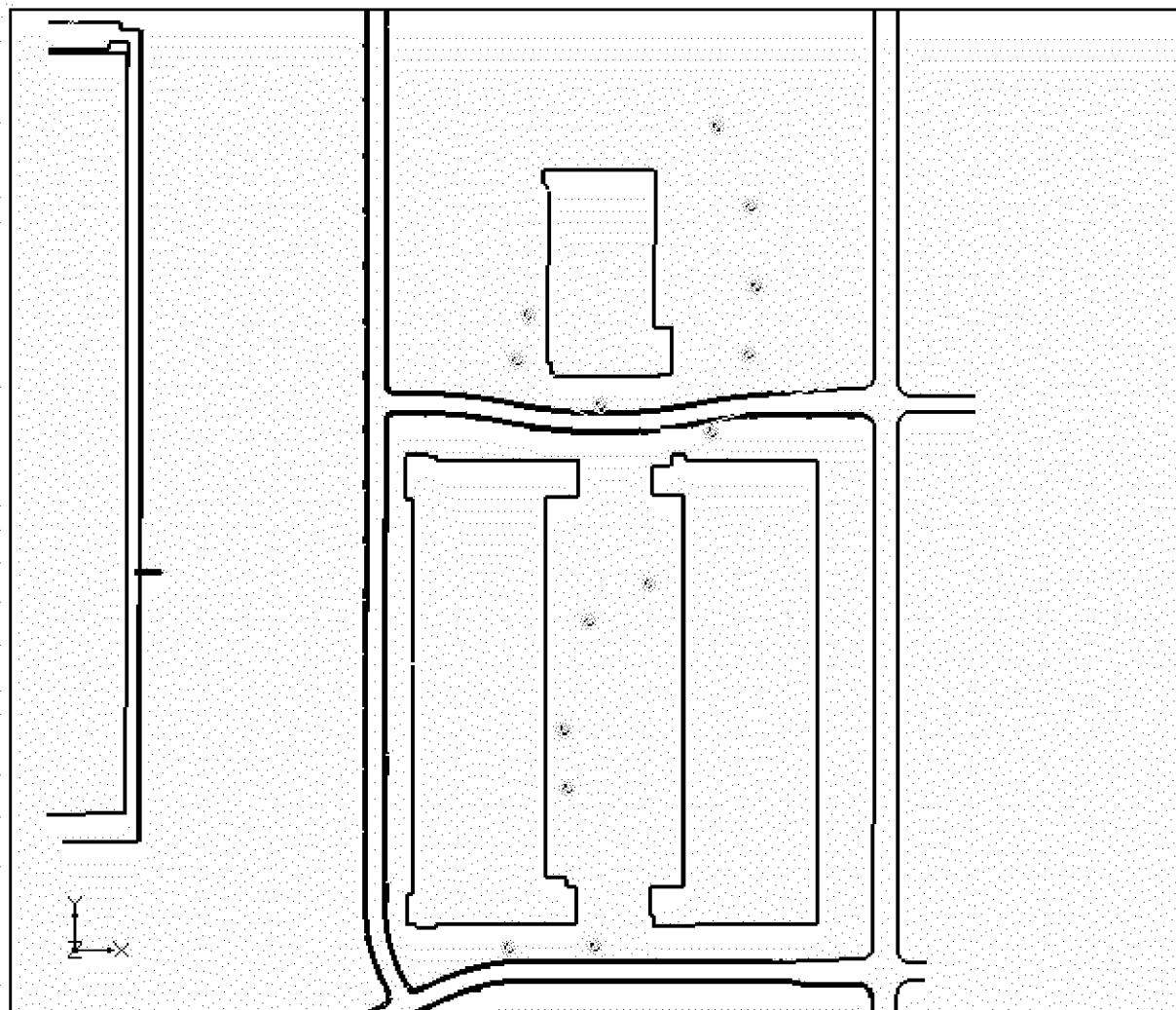
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Figure 36 – Scenario 2C (C-Sand) Estimated Donor Compound Extent
Former C-6 Facility



CDM

Figure 37 – Scenario 2B/2D/2E (B-Sand) Injection Wells
Former C-6 Facility



CDM

Figure 38 – Scenario 2B/2D/2E (B-Sand) Pumping Wells
Former C-6 Facility

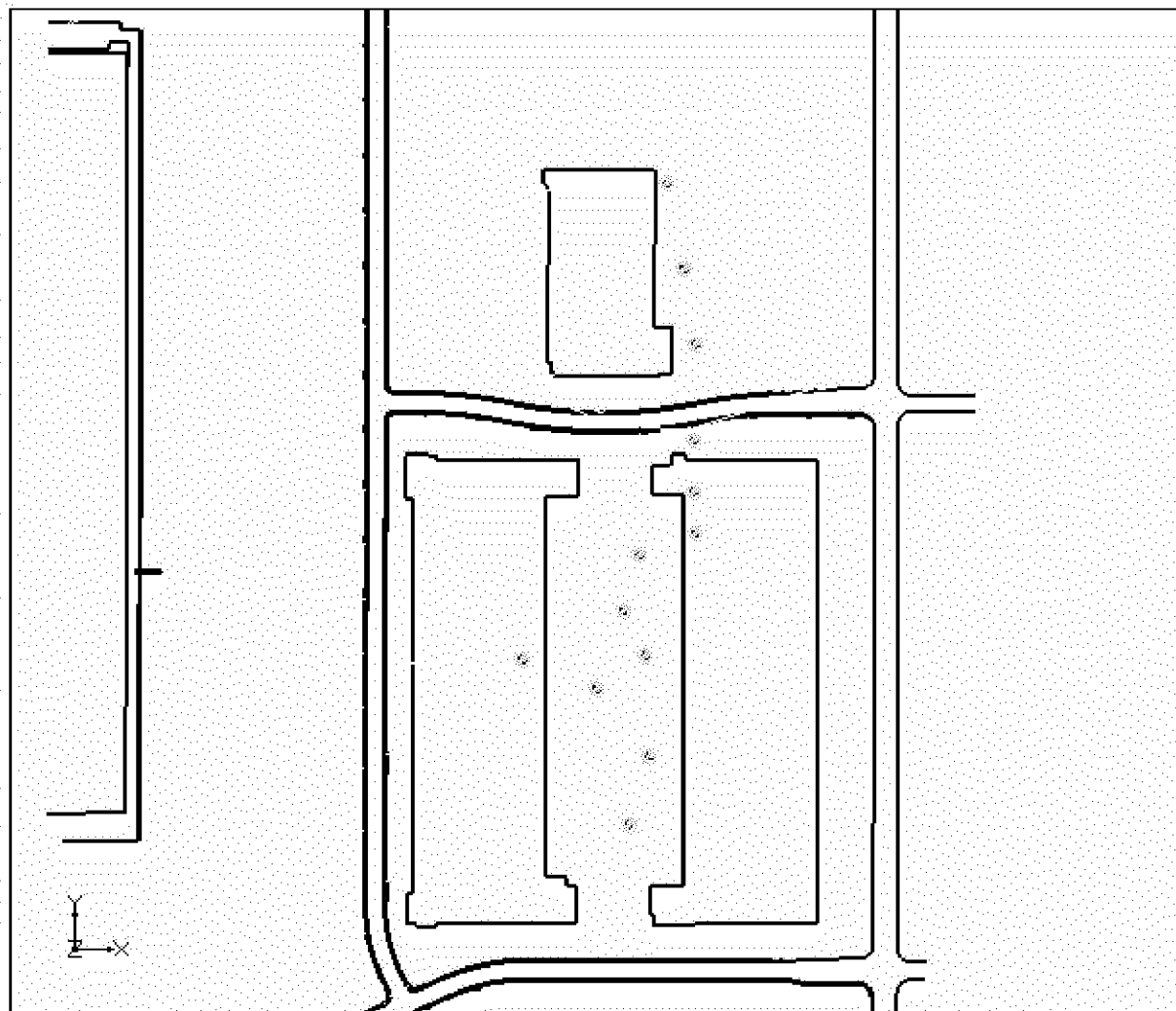


Figure 39 – Scenario 2B/2D/2E (C-Sand) Injection Wells
Former C-6 Facility

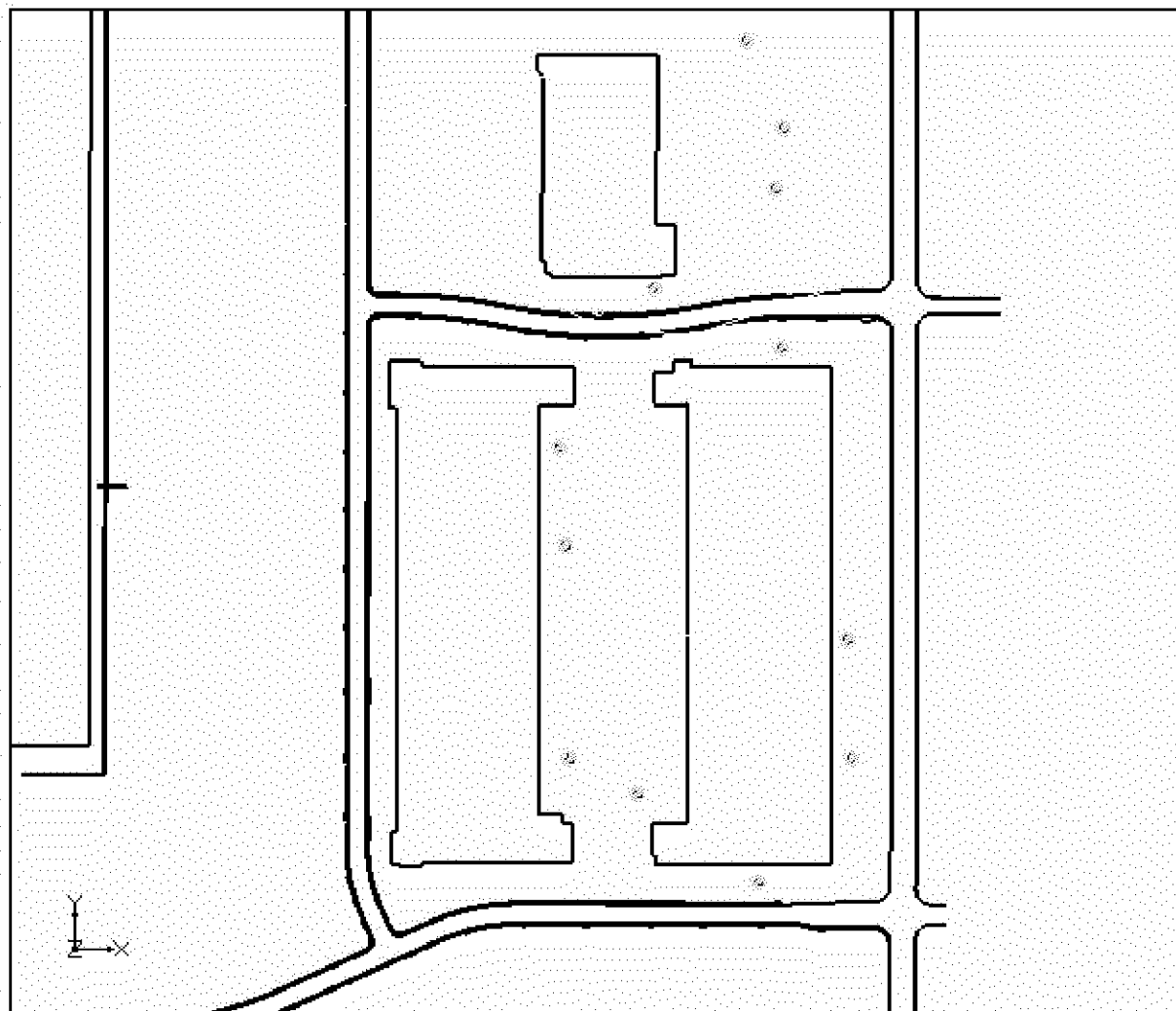


Figure 40— Scenario 2B/2D/2E (C-Sand) Pumping Wells
Former C-6 Facility

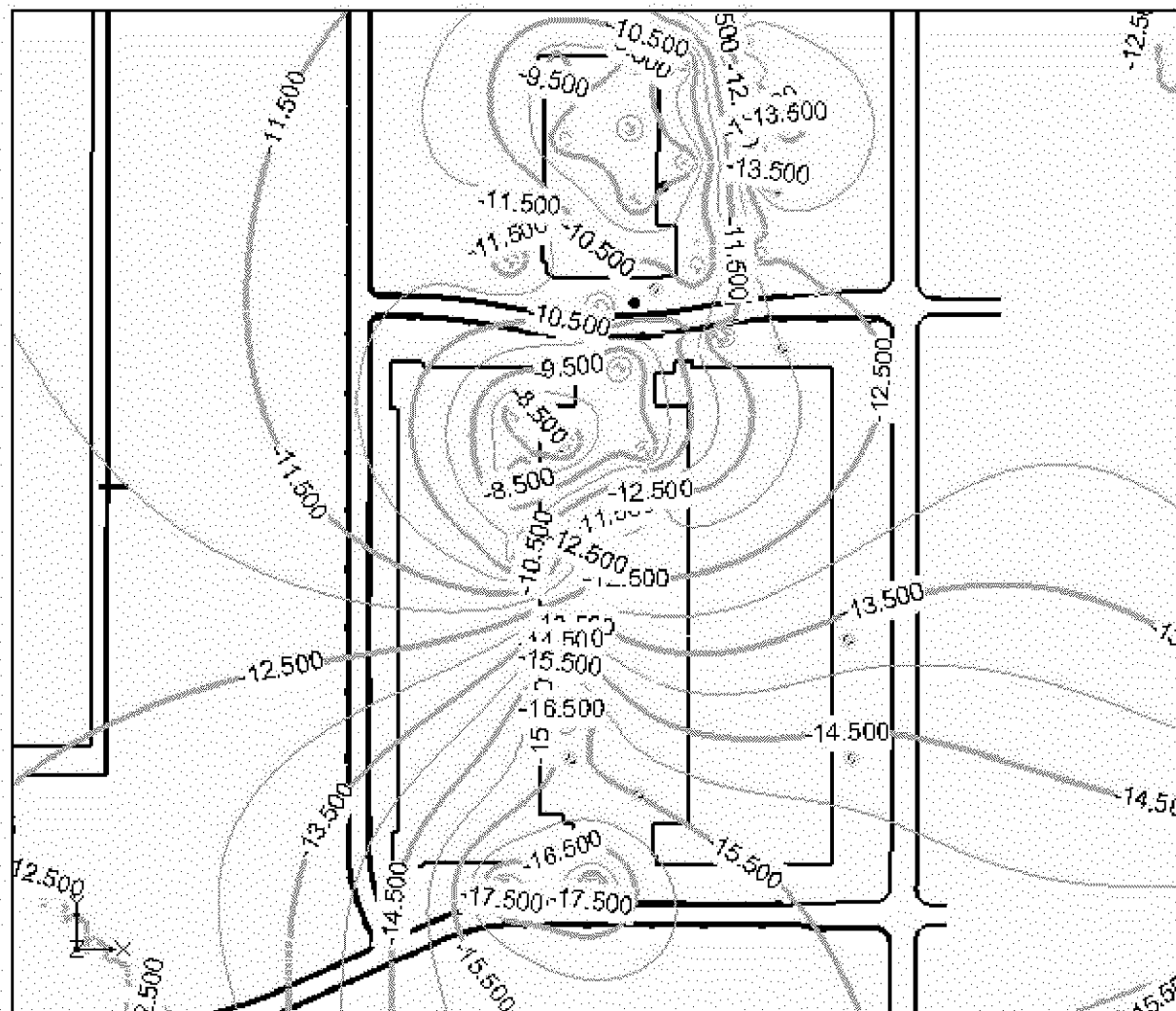


Figure 41 – Scenario 2B/2D/2E (B-Sand) Potentiometric Surface
Former C-6 Facility

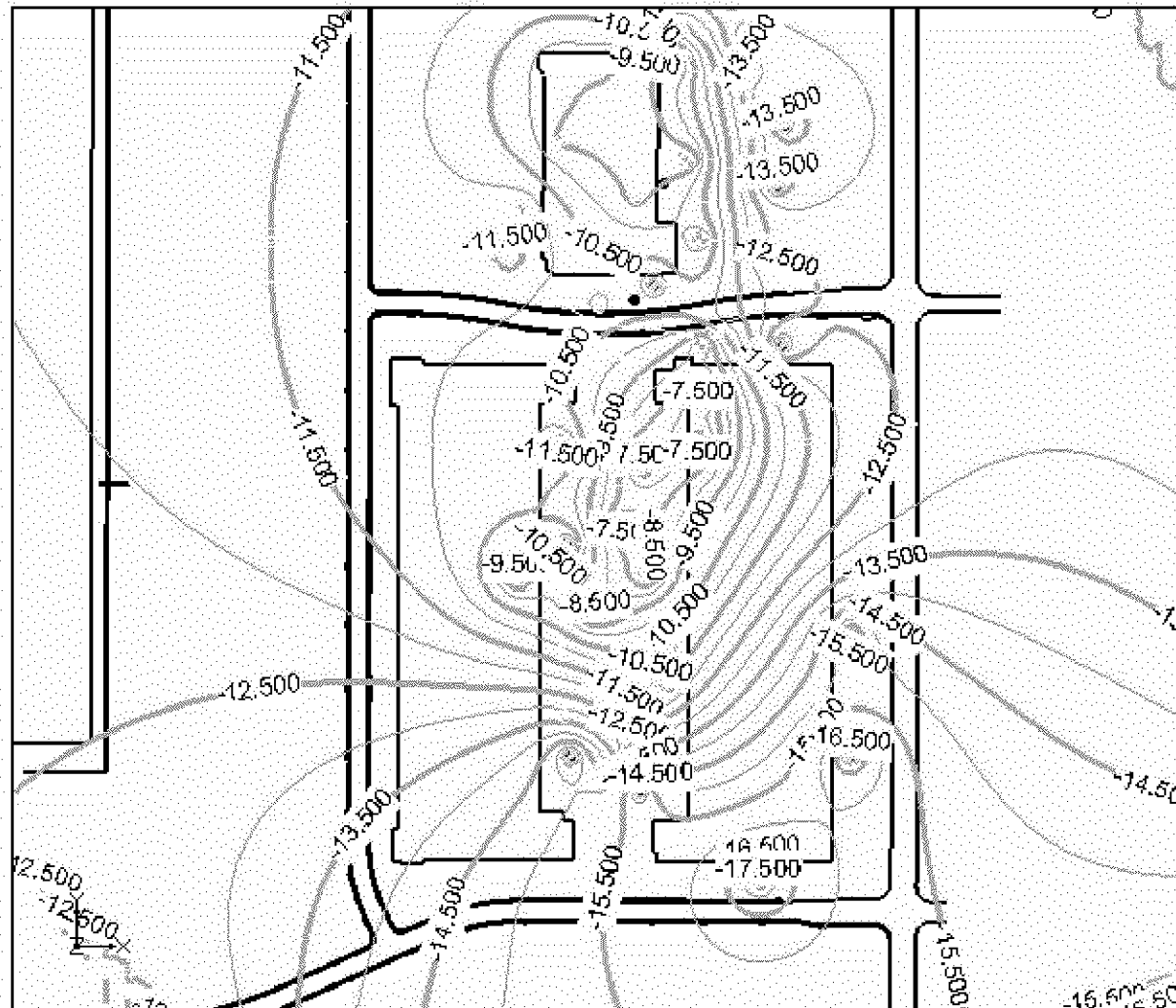


Figure 42 – Scenario 2B/2D/2E (C-Sand) Potentiometric Surface
Former C-6 Facility



CDM

Figure 43 – Scenario 2B/2D/2E (B-Sand) Estimated Donor Compound Extent
Former C-6 Facility



CDM

Figure 44 – Scenario 2B/2D/2E (C-Sand) Estimated Donor Compound Extent
Former C-6 Facility